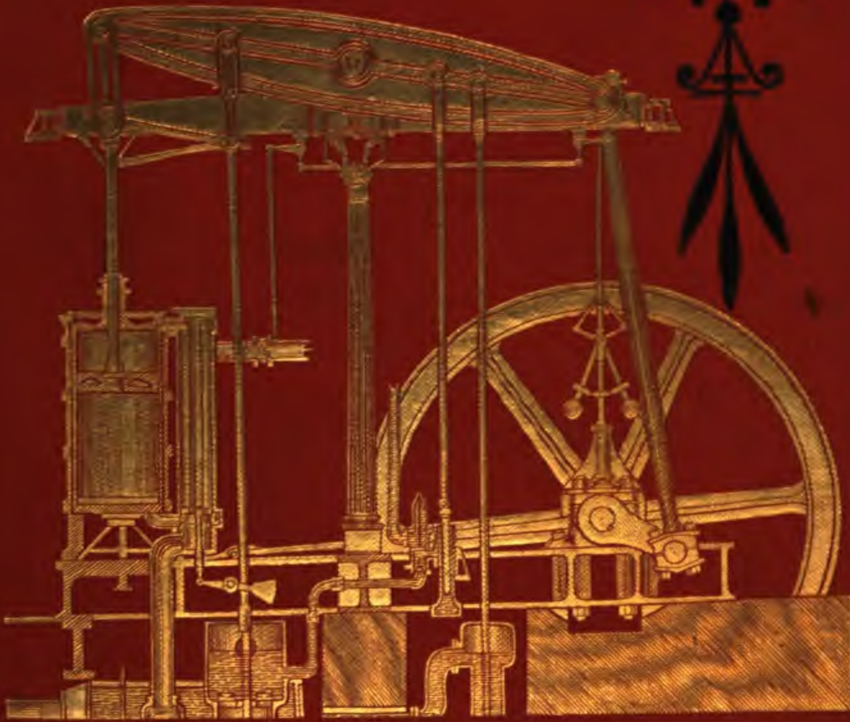
STATIONARY ENGINE DRIVING



MICHAEL REYNOLDS.

I remain your obedt. Servt.

James Watt

London Crosby Lockwood & Co. 7 Stationers Hall Court

STATIONARY ENGINE DRIVING

A PRACTICAL MANUAL

FOR ENGINEERS IN CHARGE OF STATIONARY ENGINES

BY MICHAEL REYNOLDS

MEMBER OF THE SOCIETY OF ENGINEERS,
AUTHOR OF "LOCOMOTIVE ENGINE DRIVING," "THE MODEL LOCOMOTIVE ENGINEER, FIREMAN, AND ENGINE-BOY," ETC.

With Numerous Illustrations

SECOND EDITION, REVISED AND ENLARGED

LONDON
CROSBY LOCKWOOD AND CO.
7, STATIONERS' HALL COURT, LUDGATE HILL
1882

LONDON:
PRINTED BY J. S. VIRTUE AND CO., LIMITED,
CITY ROAD.

TO

THE ENGINEMEN AND FIREMEN

OF

STATIONARY ENGINES

THROUGHOUT THE UNITED KINGDOM

THIS WORK

IS

Dedicated

AS A TRIBUTE OF RESPECT AND REGARD

BY THEIR SERVANT

THE AUTHOR

PREFACE.

I HOLD a very strong opinion that, no matter how good and well tested a steam-boiler or a steam-engine may be, accidents to boilers and machinery will take place, so long as the men in charge are not put to any qualifying test themselves. Owners of steam-boilers properly insist upon their being made of the best material, on the latest pattern, and they do not object to paying a good price for a good boiler; but in many instances the matter begins and ends here. It is not an uncommon occurrence to find men in charge of fine machinery who cannot explain a tenth part of the movements before them. Of this we cannot complain, because when a man is out of employment he is ready and willing to take charge of an engine, even if he knows nothing about it, provided he can persuade the owner of such machinery to take his word for his competency.

I have been conversant with steam-engines for a quarter of a century, and not without observing the modes by which men have been enabled, in many instances, to raise themselves to the rank of enginemen, and to have charge of engines, boilers, and machinery.

The skilled mechanical engineman's eye is trained; it is full of activity and adjusted in its range by experience, and it detects the very appearance of evil. Therefore the man

is full of expedients, full of opinions, full of facts, and wants to be nipping the evil in the bud. Part of this effect is due to the sheer quantity of mental work thrown in with the manual toil; but in many instances these acquirements are considered superfluous naughtiness, and a way of making work for making money by overtime. The unskilled engine-man is in many cases the simple, honest man, who will work the machinery without any repairs month after month until a shaft breaks, in consequence of a bearing being in need of adjustment, or of a rivet leaking week after week disregarded, until corrosion sets in; or he will overload the safety-valves, by laying on scrap iron, or by moving the weight; and so make one boiler do the work, at the risk of life and limb.

But, as I have already said, no one can blame a man for making his way into the engine-house. The law does not interfere with the matter, and the loss arising from bad appointments is borne by the master. I have reason to believe that every man who engages himself as an engine-man is induced to do so from a good motive.

My object in writing this work is to give such information as lies in my power as seems to me calculated to raise the status of enginemen in this country—the land of steam-engines—and to try and induce them to pursue their inquiries in other works, written by better pens than mine.

I have sought out and put together such information as I thought would be of benefit to those who wish to learn something of the best Stationary Engine practice. There are many enginemen who have not had an opportunity of examining a condensing engine, such as is supplied for large pumping stations, and who have had no experience either

with them or with Galloway boilers, though they cannot tell how soon they may be called upon to manipulate such works; and therefore I have supplied for their information drawings of engines and boilers, with keys thereto. The elements of the stationary engines are described, and the principles of construction of the Galloway, Cornish, and Lancashire boilers are set forth, whilst the causes of failures are analysed and exposed. The various causes tending to produce explosions of boilers are discussed at length, and the errors often committed in shutting down valves are referred to; whilst the management of the fire and the principle of combustion are fully explained.

I have also added a chapter on the use of the indicator, with examples in the arithmetical portion, of the method of calculating horse-power from diagram cards.

In the endeavour to accomplish my work in a manner both instructive and agreeable, I have now and again departed from the general course to notice some particular point: especially in those portions of the work connected with the name of Watt, whose portrait forms the frontispiece to this work.

Some time ago an effort was made to establish a system of certificates of proficiency for enginemen, by means of which I did hope to see the vocation of engine-driving brought up to a high standard, but, from the very limited number of men who felt disposed to assist at the work, it was evident that the men themselves did not care for certificates, whilst the masters did not want them. I have therefore now concluded that the only means is to place within the reach of the men such books as shall elevate their ideas, and induce a manly independence of thought and opinion.

Finally. It may possibly be asked what are the qualifications for writing upon the subject of this work. I may, in answer, briefly state that I served my apprenticeship in a general engineering shop, working at the lathe and vice, and that, afterwards, I have been engaged in various parts of England, on Locomotion, Tractive, Stationary, and Portable engine work.

MICHAEL REYNOLDS.

STANDEFORD, *August*, 1880.

NOTICE.

A Second Edition of this book having been called for, the opportunity has been taken to thoroughly revise the whole, and to make many useful additions. Chapter II. has been almost entirely re-written; whilst Chapter XII. has been largely extended to embrace a comprehensive account of the varieties of British coals, with a notice of their behaviour in the furnace, and a discussion of the methods of treatment best suited to the several varieties.

March, 1882.

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2

STATIONARY ENGINE DRIVING.

CHAPTER I.

INTRODUCTORY NOTICE OF THE STEAM-ENGINE AND BOILER.

England is the birthplace of the steam-engine. Its invention has been a grand triumph over the material which nature has placed at our disposal. There is no limit to the sphere of its usefulness, nor can any one measure the benefits which directly and indirectly accrue to society from its extended employment.

All these benefits are simply due to the operation of the natural principle, that water can be converted into a gas. The principle itself appears very simple; but the discoveries that led to the practical application of the principle as a source of wealth, were perfected only after a long series of trials and failures, and the experience thus laboriously accumulated.

It is on record that for two thousand years steam was only used as a source of amusement; it was a scientific bauble to be sure, and that was all. But great things very often spring from small beginnings. Galileo's discovery of the pendulum was the result of observing

the swing of a lamp in the centre of a church. By a spider's net suspended across the path of Sir Samuel Brown, he was prompted to the conception of a suspension-bridge. Galvani observed that a frog's leg twitched when it was placed in contact with different metals, and this laid the foundation of a train of invention which led up to the electric telegraph. Columbus saw strange reeds and stranger rushes floating in the water off the quay of Oporto, and he was instigated by the strange visitors to undertake a voyage by which the New World was discovered. With regard to the advancement of steam as a motive-power, its history presents for contemplation a marvellous train of consequences, logically deduced or tentatively arrived at, interesting in themselves, and furnishing a narrative of success and of lapse and loss of choice spirits, the fragrance of whose enthusiasm lingers to this day. "We may form," writes an eminent authority, "some faint idea of the anxious hope and fear of each succeeding genius before his conceptions were clothed in mental or material form—the parental grief or joy as each child expired in infancy or arrived at manhood and fame."

Towards the close of the seventeenth century there was a prodigious and sudden development of the mind of man, due, writes Lord Hatherly, to the Reformation.

Some of the illustrious men of the time were mighty in words and in deeds. Newton—of whom it was written that "God said, 'Let Newton be!' and all was light"—Shakespeare, and Bacon; these, together with a few others, turned the world of ideas upside down. The Royal Society was founded, where the chaff was win-

nowed from the wheat. It was a light ablaze, a beacon for great designers, a resort "to whomsoever hath in recommendation either knowledge, profit, or pleasure."

From this time the force of steam has been employed: first, it is true, only to burst a cannon, but at last to drive a cotton-mill with 10,000 spindles.

At first steam was regarded as a wild Turcoman horse, having a magnificent spirit, with huge sinews and muscles, the puff of whose nostrils was caloric.

Some were decided by their fears, being mortally afraid of it; whilst others determined upon a policy of aggression and investigation. The principal "Alexanders" were Papin, a French physician; Savary, an English miner; Newcomen, an English blacksmith; Potter, an English peasant-boy; Fitzgerald, an Irish professor; Watt, a Scottish mechanic; Picard, an English mechanic; Cartwright, an English Dissenting clergyman; Murdoch, a Scottish mechanic; Hornblower, an English mechanic; Trevithick, a Cornish engineer; Stephenson, an engineman.

Among the innumerable inventions of man for administering to the necessities and luxuries of life, none has played so important a part as the steam-engine. By its power the great deep is crossed in sunshine or in storm, independently of tides. It lifts mineral treasures from the bowels of the earth to the surface, for the service of man. It drains the mines, so that the lodes containing the ore are made accessible. Communities are brought closer together, and the advantages which were confined to a few are now extended to many. Illimitable is the adaptability of the steam-engine; and every day improvements are being made in its structure and application. In dealing with

the subject, it will be our duty to notice for the information of young enginemen such types of engines and boilers and their appendages as prevail at the present day.

Classification of Steam-Engines.—Stationary engines are distinguished as either vertical, horizontal, or beam engines.

When the cylinder is suspended above the crank-shaft it is a vertical engine. When the cylinder is fixed in the same horizontal line as the crank-shaft it is a horizontal engine, or, as the enginemen call it, a "lie-down."

When the cylinder is up on end, and the piston-rod is attached to a beam which is suspended at its centre, it is a beam engine. When the cylinder is on end, and the piston-rod is attached to one end of the beam, while the other end of the beam is suspended on a pillar, it is a grasshopper engine. When the cylinder is suspended at the centre by trunnions, with the crank-shaft either above or below the cylinder, it is an oscillating engine.

For each of these types, terms are employed to denote their specialities.

When the cylinder is suspended vertically in the upper part of a cast-iron frame, it is an inverted-cylinder engine, or what is the same thing, an inverted direct-acting engine. Sometimes two cylinders are placed alongside of each other in this position, between the frames, with the steam-chest between them, and the crank-shaft being below.

There is also a type of engine called the "trunk engine," specially constructed to reduce the distance between the centres of the crank-shaft and the cylinder

in direct-acting engines, retaining at the same time sufficient length of connecting-rod.

Its principle is as follows:—A hollow cylindrical casing or "trunk," from which it takes its name, is fitted fast upon the piston. The trunk works through both ends of the cylinder, and is fitted with a stuffing-box at each end. One end of the connecting-rod is attached to the face of the piston within the trunk, the other end of the connecting-rod being attached to the crank-pin. The internal diameter of the hollow trunk is sufficiently large to permit the vibration of the connecting-rod within it. Thus, as already mentioned, whilst a long connecting-rod is obtained, the distance between the centres of the crank-shaft and the cylinder is reduced. Such engines are often used in steamships.

Again, some engines, which may be constructed according to any of the foregoing types, are constructed as compound engines. They consist of two cylinders, in which the steam, after having been used in one cylinder, is used again in the second cylinder, instead of being exhausted at once into the atmosphere or the condenser.

The engine which now claims our special attention, and which has been selected for illustrating the description of the steam-engine in detail, and for instructing enginemen in the management of engines, is the beam engine, inseparably associated with the name of Watt. There is no other engine that commands our admiration as engines of this old-fashioned design, when carefully designed and artistically surrounded. Since the year and the day it left the hands of Watt it has afforded scope for the exercise of ingenuity, talent,

and perseverance. There has not been much to alter. The material is the same, so is the moving power, and so also is the principle; but one thing has improved in the hands of his successors, which the great man probably never dreamt of, and that is the rapid and seemingly exhaustless demand for engines.

The blowing out of a cork from a flask of water, the temperature of which had been raised by the heat of the sun, indicated to man a field of labour and research, in which many labourers have been working. At first the practical results were of a very limited character; the workers were too wide apart. The labours of isolated individuals were frequently confined to theoretical reasonings and calculations, not infrequently biassed by prejudice, party spirit, or egotism, or untenable hypotheses.

Progress at first, therefore, was slow, and the mode in which the lesson was applied exhibits a characteristic feature of the human mind, which is apt to prefer the uncertain road of abstract reasoning to the direct course of experiment. Each scholar reasoned for himself; hence many diversified opinions, replete with so much that is erroneous, unscientific, and contradictory. The truth cannot be made; the truth exists.

As the properties of steam became revealed to the mind, new wants were created. Brindley confined steam in wooden vessels, but there were threatening difficulties attendant on the use of such an unstable material as wood. Stone vessels were employed in an endless variety of forms; and these in their turn were superseded. For a long period of time, steam was used as a motive-power in a negative sense, as was shown in the atmospheric engine, in which steam of a low pres-

sure was employed to produce a vacuum under the piston.

The difficulty of constructing vessels of sufficient strength was one of the chief impediments in the way of using high-pressure steam; and although the spherical cast-iron boiler was an advance upon all others, it was found to be untrustworthy, and was replaced by wrought-iron boilers. The variety of shapes in which boilers have been made is the outcome of a desire to obtain a safe boiler, an effective boiler, a convenient boiler, and a durable boiler. The boiler which combines these four qualities, and possesses each quality in an eminent degree, may be considered a perfect boiler. The material used in making boilers is the outcome of the need for obtaining great tensile strength and ductility. These are the first considerations. In an economical point of view, for generating steam, irrespective of cost, copper is the most eligible metal for conducting heat, as its conducting power is more than double that of iron; but this advantage is counter-balanced by the fact that copper suffers such a loss of cohesive strength by elevation of temperature, even to a moderate extent, as to cause it to be superseded by wrought-iron, except for special purposes unconnected with strength. Besides its heat-conducting power, which recommends it to the notice of locomotive builders, it is also recommended by the mode in which it is fractured when an explosion takes place; it tears open, whereas iron is blown to pieces.

Wrought-iron boilers at first were either globular or hemispherical, with flat or with concave bottoms. They were as nearly spherical as possible, and so presented the best form to resist the internal pressure of

the steam. They were deficient in heating surface, and were great wasters of fuel. Under these circumstances Watt was induced to design the "waggon" boiler, which was so called from its likeness to mill waggons, which were covered in to keep the contents dry.

This boiler, having by its form a greater area of heating surface, was capable of evaporating more water per hour than any of its predecessors; and, besides, the gaseous products of combustion, having a long run of heating surface, remained longer in contact with the plate surface, so that before they reached the chimney they were cooled down by the absorption of their heat to a temperature very much lower than that of the gases which escaped from the earlier kinds of boilers. Watt held that there was a considerable waste of fuel in producing steam by intensity of heat directed upon a small surface; and he preferred to apply heat at a moderate temperature, providing a large area of surface on which it should act.

The cost of fuel for producing steam for the large Cornish engines being an item of importance, the Cornish engineers gave the matter of steam generation every consideration. The "Trevithick boiler" was brought out. It was advertised to be superior in economy, and capable of bearing a pressure of 30 lbs. per square inch. This boiler is now known as the Cornish boiler; cylindrical, with flat ends, having an internal flue and fire-grate. The flame, proceeding from the fire at one end of the flue, traverses the whole length of the flue, and the gases are returned along the bottom of the boiler to the front, thence along the sides to the chimney, by which the actuating force of draught is generated. Sometimes the flame takes

the side courses first, after leaving the flue, and then passes under the boiler to the chimney. Whichever way it is done, the object is to expose as much boiler surface as possible to the hot gases, so that they shall not leave the boiler until they are reduced as nearly as possible to the temperature of the water in the coolest part of the boiler. By this means the consumption of fuel can be reduced and the evaporative power of the boiler improved. In consequence of the weakness of a single internal flue, when of large diameter to receive a large grate-area, two flues instead of one flue were adopted in Lancashire, and hence the name, "Lancashire boiler," given to a boiler with two flues, to distinguish it from the "Cornish boiler," which has one flue only.

Still more to economise the heat and increase the amount of heating surface, the "Galloway boiler" was designed. It is a great favourite with steam-users, and it satisfies all the requirements of the day. To design a boiler for high-pressure steam, that should be at once as safe as, and yet more economical than, its predecessors of the same class, demanded no small amount of physical and mechanical knowledge.

CHAPTER II.

MATERIALS OF WHICH ENGINES AND BOILERS ARE MADE.

It will be well for the information of enginemen to give a brief account of the methods employed to extract iron from the ore, to trace the processes employed in producing wrought-iron and steel, and to offer a few remarks upon other materials in which they are interested.

Calcined Ore.—Before the ore is placed in the blast-furnace, it is necessary to calcine or roast it in a kiln, in order to expel the water, carbonic acid, sulphur, and organic matter contained in it. The sulphur is occasionally expelled by means of a jet of steam, with atmospheric air, the sulphur passing off in combination with the hydrogen of the steam.

Smelting.—This is a chemical process, and it consists principally in depriving the metallic oxide of its oxygen. The ore having been deprived of its volatile constituents, it is carried to the top of a blast-furnace, some 50 feet or more in height, of the form of an ordinary cupola. Some blast-furnaces are 8 feet in diameter at the hearth, and 22 feet 6 inches at the widest part. The opening at the top of the furnace is called the throat. Air is blown, by means of an engine, through

the tuyeres situated near the bottom of the furnace. The tuyeres are cased, so that water may be caused to circulate round them, to keep them cool, and to prevent their being burned away. The fuel used is coal or coke; sometimes a mixture of these. The ore is placed in alternate layers, with limestone as a flux. The quantity of fuel used averages about 21 cwt. to each ton of pig-iron.

The blowing cylinder may be termed a double-acting pump. It is driven by a beam engine or by a horizontal engine, supplied with steam from boilers which derive their heat from the combustion of the gases discharged from the blast-furnace. The pressure of the blast is from half an inch of water to 2½ lbs. per square inch. The temperature of the blast-furnace about the tuyeres is about 5,000 Fahrenheit degrees. When there is collected a quantity of liquid metal at the bottom of the furnace, it is tapped, through an aperture provided near the hearth, by the furnace-man with a long rod. The metal rushes out into a channel made for it called a *sow*, and into branch channels called *pigs*. The metal is cut off when it runs "thick" or "cold."

The iron thus produced is very crude, and is remelted to render it suitable for castings. If intended for the manufacture of wrought-iron, it is sent to the refinery. Cast-iron contains many impurities, consisting principally of silica, manganese, carbon, sulphur, phosphorus, aluminum, &c. It is granular, brittle, rigid, and offers but little resistance to tensile force, but stands well under a crushing power.

Puddling.—For the purpose of separating the carbon and other matters in combination, in the process of

manufacturing malleable iron, the pig-iron is broken up and placed in a reverberatory furnace, which is rectangular in shape. The broken metal is placed on the middle of the hearth, whilst the fuel for the generation of heat is placed on a grate at one end of the furnace, so that it does not come into contact with the metal. When the metal begins to melt, air is admitted, and the metal is stirred or moved about in order to expose it to the air. In time it boils, and it is kneaded into a fibrous mass, whilst the supply of air is reduced. The puddler kneads the iron into balls or "blooms," until the interior of the furnace looks like a baker's oven full of loaves.

Rolling or Squeezing.—The bloom is passed by the puddler to the shingler—from the furnace to the hammer. Under the hammer, the bloom is consolidated, the slag being driven out of it, and it is left in such a form that it can be dealt with by other machinery. If it is intended to be passed through the rolls, it is left in a rectangular shape. If it is intended for a weldless iron tyre, it is left of a cheese shape, and a hole is punched through the middle; a roller revolves within the cheese-formed mass, and another outside. The outer roll is formed so as to shape the flange of the forthcoming tyre. As the two rollers revolve, they are pressed towards each other until the tyre is reduced to the required thickness. If the bloom is intended to form bar-iron, it is passed between rolls until it is drawn down to the size required. By turning recesses in the face of the rolls of various depths and shapes, round, flat, or square bars, and angle-iron of all sizes, can be produced.

Piling.—Iron gains in purity by repeated hammering

and rolling. Rough iron, after it has passed through the rolls for the first time, or scrap-iron consisting of odds and ends, cut into short lengths, and made into a pile, and when sufficiently heated passed under the hammer again or through the rolls, is better iron after the process than it was before. Tenacity is acquired in proportion to the treatment to which the metal is subjected in refining and in hammering. "Best" iron, and "best-best" iron, are terms used to denote the quality of the iron, and the quantity of work which has been bestowed upon the iron in the forge mill.

Charcoal-Iron.—This term was originally applied to such iron as had been manufactured solely with wood charcoal from the condition of ore to the finished state. But the term is now applied to iron, the ore of which may have been smelted with coal or with coke that has been refined or puddled with wood-charcoal. Charcoal iron has a very smooth skin; it is used for purposes where the surface is to be painted.

Steel.—Steel is formed from wrought-iron by combining carbon with the metal in certain proportions. By the ordinary method, wrought-iron is cut into short lengths and packed in charcoal, and submitted to a bright heat, until the metal has taken up a quantity of carbon, by which it is converted into steel. The steel is then worked under a hammer in order to render it homogeneous, or uniform in substance throughout. By the Bessemer process, cast-iron is melted and run into a converter, and the impurities are expelled by combustion with a current of air forced through the melted mass. The colour of the flame above the molten metal varies with the proportion of impurities present; and by this colour it is known when the

process of combustion has been carried far enough for the production of a given kind of steel.

It may be said that cast-iron, wrought-iron, and steel have only two essential ingredients, namely, pure iron and carbon. Cast-iron contains more carbon than wrought-iron or steel; the carbon may exist in pig-iron either in a state of chemical combination or as flakes, distributed in an uncombined state through the mass of iron, or partly combined and partly graphitic, and these varying conditions produce white, grey, and mottled pig-iron. Wrought-iron contains less carbon than cast-iron or than steel; and the amount of mechanical treatment it has undergone is indicated by the colour, varying from bluish to blackish shades of grey. Steel contains more carbon than wrought-iron, since wrought-iron is placed in the furnace with charcoal for the purpose of its taking up carbon to form steel. It may be said that steel is a pure iron with a small portion of carbon in it. The following is an average composition of iron in its three conditions:—

	Iron.	Carbon.
Cast-iron.	91	5·
Wrought-iron . . .	99·5	0·035
Steel	98·5	1·4

Cast-iron, wrought-iron, and steel can be distinguished from each other, in the first place, by the fineness of the grain; wrought-iron being finer in grain than cast-iron, and steel finer than wrought-iron. Again, cast-iron is short and brittle, wrought-iron is fibrous,

whilst steel is devoid of the fibre so characteristic of wrought-iron, and, like cast-iron, it is granulated or crystallized metal. Steel and cast-iron possess the property of fusibility; wrought-iron is malleable, ductile, tough, fibrous, and possesses the capability of welding in the highest degree. Steel, also, when red-hot, is nearly as malleable as wrought-iron, and may with care be welded. From this it will be seen that steel possesses properties in common with both wrought-iron and cast-iron. Further, steel is characterized by its softness at a glowing heat, and its becoming hard upon sudden cooling. Cast-iron resists a greater crushing strain than wrought-iron; wrought-iron resists great torsional and tensile strains; while steel of average quality can resist a great tensile strain—nearly twice that of wrought-iron, and seven times that of cast-iron. By the term "breaking strain" is meant the strain or stress which will break the iron or fracture it. By the "proof strain" is meant the greatest strain of a specific kind consistent with safety. By the "safe working strain" is meant the strain which may with perfect safety be placed upon the material. The ratio of the breaking strain to the proof strain is termed the "factor" of safety. Iron in all its forms—cast-iron, wrought-iron, and steel—is made up of minute particles or atoms, and their cohesion is limited. Bend the material beyond the elastic limit, and it is damaged—either bent or broken. But so long as the working strain does not exceed the elastic limit, the arrangement of the atoms is not permanently disturbed; and the metal will, when the load is removed, resume its original form without being damaged. The strength of metal has been tested, and from the experiments a working

load has been given, and a wide margin of safety is allowed, not only for the sake of security under ordinary circumstances, but to insure machinery against the effects of unforeseen strains.

Case-hardening is a process for converting the surface of iron into steel. To case-harden properly, the iron must be thoroughly clean and bright. The parts of an engine generally case-hardened are those which are small in size, but subject to great friction. The articles to be case-hardened are placed in a wrought-iron box, and embedded in substances rich in carbon—as fragments of horn, bones, and leather-cuttings. The box is luted air-tight and placed in a furnace, where it remains for about twelve hours, after which time the fire is allowed to burn out. Then the box is removed and opened, and the contents taken out. The portions of surface not intended to be hardened should be covered with clay. The steeled surfaces, when taken out of the box, are brightened with emery cloth.

Steel is tempered by heating until it has acquired a cherry redness, and then plunging the part to be tempered suddenly into a liquid (oil or water) and withdrawing it almost immediately. The colours will then be developed in the following order, commencing with the colour for the hardest description of steel: very pale straw yellow, suitable for cutting tools for metal; dark straw, for wood tools and taps; yellow, with a slight purple tinge, for chipping chisels; dark purple, for springs; bright blue, for watch springs; dark blue, for hand-saws, producing a soft bending steel, hard enough to cut wood, and not too hard to resist the file.

Annealing is a process, the reverse of case-harden-

ing. The articles operated upon are converted from a condition of brittleness to a condition of comparative toughness. The process is employed in order to file, or to re-turn in the lathe, any portion of an engine that has been previously hardened. In the annealing of steel or iron the metal is heated to a low redness, and allowed to cool gradually. The operation is performed not only to soften the article, but also to restore its elasticity.

It should also be mentioned that, whilst in a soft condition, wrought-iron, steel, and copper can be worked under the hammer into any required form; but the process of welding, which means the joining of two pieces of metal together, is only applicable to iron and to steel. Heated to a white heat, iron and iron can be welded together; so also can iron and steel be welded together; but the steel must not be overheated, otherwise it will burn.

Copper.—Of other metals entering into the construction of engines, copper, like iron, is not found in a pure state. The ore is first crushed and then washed, either by hand or by machinery. It is then roasted in a furnace, in order to expel foreign matter, and is melted in another furnace. The scum is skimmed off, and the metal is run off into a pit containing water, which causes the metal to become granulated, in which state it contains about one-third part of copper. This product is calcined, in order to oxidize the iron which the copper contains, and it remains in the furnace for a number of hours, after which it is taken out and melted with slag from previous meltings, which acts as a flux. It is then skimmed and run into moulds. The quantity of copper at this stage is about 60 per cent.

The calcination and fusion of the last product is proceeded with, and the metal is run into "pigs" containing from 60 to 80 per cent. of copper. These pigs are roasted, and the temperature is increased to the melting point, which facilitates the expulsion of volatile matter, and oxidizes the iron or other metallic substances that may remain in combination. This operation is continued for some hours, according to the degree of purity of the "pigs," and when completed the metal is run into sand-beds. The copper, now freed from most of the foreign matter, is placed in a refining furnace, where the heat is at first very moderate, in order to continue the oxidation, should the metal not be quite pure. When, however, it reaches the melting temperature, the copper runs into a small trough, and a portion is extracted, cooled, and broken, and the attendant judges from the result whether the material is in a fit state to undergo the toughening process. If it is so, the surface of the metal is first covered with charcoal, after which it is stirred with a birch pole. The operation of polling is continued with the addition of fresh charcoal until it has attained the required degree of purity, when it is cast into rectangular cakes, measuring about 12 inches by 18 inches. Pure copper is unfit for many purposes, and hence the use of other metals, in combination with it, as tin and zinc, to extend its usefulness.

Tin.—Tin ore is stamped or broken, and then washed to separate it from the earthy matter, after which it is roasted in a reverberatory furnace and is afterwards smelted. Nine parts of copper and one part of tin form gun-metal.

Zinc.—The ores of zinc are first roasted or calcined,

and the zinc is subsequently distilled from them in retorts. Sixteen parts of copper and nine parts zinc form brass.

Lead.—The ores of lead, like those of other metals, are combined with various kinds of earthy matter, and therefore they are, in this case, washed, and then roasted in a furnace, which by oxidation converts it into oxide and sulphate of lead; which, reacting on each other, cause the production of metallic lead.

Brass, gun-metal, and white-metal are all alloys. The term alloy designates a combination of two or more metals, having a chemical attraction to cause them to adhere to each other. As previously stated, bodies are made up of atoms. When atoms of the same kind hold together, that is cohesion; but when atoms of a different kind join or hold together, it is called chemical attraction. One atom of copper is attached to another of copper by *cohesion;* but when an atom of copper unites with an atom of zinc, it is an instance of chemical *attraction*, or, as it is sometimes called, chemical affinity. Chemical attraction is distinguished into three degrees—namely, mixture, solution, and chemical union.

Chemical *mixture* takes place when the atoms of two bodies are in a liquid state, and have freedom of motion between themselves, upon which fluidity depends. A crucible containing molten metal, such as brass, zinc, and tin, contains a chemical mixture.

Chemical *solution* operates between solids and liquids. A glass containing water with a piece of sugar dissolved in it contains a chemical solution.

The power of solution is limited, as liquids cannot combine with more than a certain quantity of solid

matter. When the point of limitation is attained it is called the *point* of *saturation.*

It is worthy of notice, that when water has dissolved saltpetre up to the point of saturation, it will dissolve a considerable quantity of common salt. How is that?

Here is a basket full of tomtits' eggs, which represent the globules of water; into the basket of eggs we can put peas until it will hold no more; we, however, put in some corn until it will hold no more of that; but even then we can add mustard seed, and the basket will be no fuller than it was at first.

So it is with water holding in solution other matter.

The highest result of chemical attraction is union, which may take place between bodies under every modification of cohesive attraction.

Bodies that unite in this manner combine only in fixed proportions, and the combination will often produce a total change in the properties of the combining substances, and produce heat. Combustion of coal, to wit.

On the application of a certain amount of heat to coal, gas is generated, which forms a union with the air; but if the latter is deficient in quantity the result is water. Why? The *gas* is hydrogen, the *air* contains oxygen, and the two, in fixed proportions, form the water which fills our rivers and brooks, in which fish swim and dive, and dive and swim. If we add a little more air—another atom—the result is carbonic acid.

Suppose the air to be supplied to a furnace so that no smoke is visible, we should say the *proper quantity* of air was being admitted into the furnace rendering combustion perfect, and evolving heat; and when

that is so, chemical union is in the highest degree accomplished.

We were referring to alloys, and having explained the term, with other matter more or less intimately connected with the subject immediately before us, we can now turn to the crucible pots, and after taking the lid off look into them.

The first contains an alloy for brass, which consists of—

9 parts of zinc 16 parts of copper	} Brass.

Brass is a very common alloy, and is not used much about engines.

The next pot contains an alloy for gun-metal, which consists of—

9 lbs. of copper 1 lb. of tin	} Gun metal.

Gun-metal is very extensively used for bearings and bushes.

The next pot contains an alloy for white metal, which consists of—

2 lbs. of antimony 8 ozs. of brass 10 ozs. of zinc	} White-metal.

White-metal is used on account of its softness, which renders it deficient to support a weight of itself, and it is therefore applied mechanically to a bearing in various ways.

Sometimes a row of holes, drilled in a zig-zag fashion in the crown of a bearing, are filled up with white-metal. This is done to reduce the friction to a minimum. It must be understood that there is not such a thing as a *perfectly* smooth surface. We turn a shaft

and bore out a brass as true and as perfect as we know how to do; but, as seen through a microscope, the contiguous surfaces are as rough as a "bear's back" and as hard as "flint." By drilling a dozen holes or more the area of this hard and rough surface is reduced, and by filling them up with softer metal considerable resistance is removed. In fact some bearings will not run cool unless filled up with white-metal.

It is very necessary to obviate heat by friction in machinery, which may be produced when an engine is put together with all its parts duly and accurately fitted together, with no side or end play or slackness. Now all metals expand by heat, whether heated over a fire or by friction. Allowance for this general effect of caloric, common to all bodies whatever, has received considerable attention of late years; but formerly it was literally ignored, and the cost has been great. Nature will have her course. If a man keeps his eye about, he soon finds her paths are plain and pleasant. But if he puts up a large brass, cottered tight up, and neglects to allow room for expansion by heat, he will find that the brass will make his ways far from pleasant.

It should be remembered that there are parts of an engine which must necessarily expand. If an engine-man duly considers this, it will guide him in many instances towards a right issue. Nothing either in the engine or the boiler is of the same size when cold as it is when hot. Therefore, instead of this principle being thought lightly of, it should command very great consideration. I know a case in which the connection between two boilers in steam was torn asunder through the allowance for expansion being neglected.

Another case was that of a large valve being fitted too tightly into the bridle when cold; so that the valve broke the bridle by over-expansion. Sometimes we see packing being driven into a stuffing-box, with the aid of a hammer and chisel; consequently, when it is heated by steam, the rod is gripped as by a pair of clamps, as a result of expansion. Lubrication becomes impossible.

Further, sudden expansion by heat, it should be remembered, is often attended by serious consequences. Many a cylinder-condenser has thus been cracked. Many a boiler has been started leaking. Sudden expansion has made many an employer's heart and head ache, and brought remorse to the engineman.

Heat travels from point to point in various ways, which may be graphically explained—thus. If we make a fire in the bars within a Cornish or any other description of boiler containing water, a portion of the heat from the fire is communicated to the crown-plate by *radiation* from the surface of the fuel. It passes through the iron from the inside of the plate to the outside of the plate, and into the water, by *conduction.* It passes from the surface of the fire in the gases which rise from the fire, upwards and onwards through the flues, by *convection.* It passes through and from the boiler-shell by radiation into the boiler and engine house.

Conduction.—If a piece of iron heated red-hot is suspended against an iron column, the heat is conducted into the column. Or, if a bar of iron is heated at one end the heat will travel along the bar towards the cooler parts. Conduction means the flow of heat through matter, from places at a higher temperature to

places at a lower temperature; or it may be defined to be the transfer of heat between the parts of a body, or between two bodies which touch each other. It is distinguished as internal and external conduction, according as it takes place between the parts of one continuous body, or through the surfaces of contact of two distinct bodies. The rapidity of internal conduction is very much greater than that of external conduction. Bodies conduct heat with different degrees of facility; hence some are good and others are bad conductors.

Taking the conducting power of gold to be 100, that of copper is 89; of iron, 37; of lead, 18; and of brick-earth, 1.

Wood possesses but little conducting power. One end of a stick can be held for some time whilst the other end is burning. Its inferior conducting power is taken advantage of when wood is used to form the handles of cocks and for "cleaning" a steam-cylinder.

Bodies of a porous nature—wood for instance—and especially fibrous substances, as wool, are extremely bad conductors. When an engineman is thoroughly acquainted with the conducting power of substances, he learns on what substance to bed and surround the boilers, so that the least possible heat may be conducted from them.

Conduction may be defined, in short, as a giving *out* of heat.

Metals are good conductors of heat, and therefore good radiators—giving off heat to the surrounding medium. To prevent the loss of heat in this manner from steam-cylinders and steam-pipes and the tops of boilers, they are clad with felt or with wood; or, in the

case of boiler-tops, covered with burnt earth, such as disused fire-bricks ground up into small pieces.

Water is a bad conductor of heat. When steam is first raised in a boiler, the hand may be applied to the lower part, although the temperature of the water be 240° or 250° at the upper part. It is because of the non-conducting character of water that heat is applied to boilers as near as possible to the bottoms of them.

Convection is the carrying of heat. The water in a boiler is heated by the hot particles immediately in contact with the hot-plates rising to the top of the water with the heat imparted to them by conduction. When the heat enters a part of the water, the water expands, and therefore it becomes lighter than the upper stratum of water near the top, or even just above it. This change in its specific gravity or weight, in proportion to its bulk or volume, causes the heavier portions to displace it; and by a successive displacement it is eventually lifted to the surface of the water. The act of boiling creates a current of hot globules upwards, expanded and charged with heat taken from the furnace-plate; and a current of cooler globules descending to absorb, in their turn, and to diminish the quantity of heat applied to the plate by the fire in the furnace. It is clear that if the globules of water are embarrassed in ascending or descending conduction is hindered, and the plate is liable to be damaged by overheating. Evaporation depends for its efficiency not altogether on the quantity of heat applied to the plate, but also upon the quantity of heat taken from it by ascending and descending particles of water. Hence the necessity for favourable circulation, and the absence of overcrowded flue-tubes.

Again, the heat from the walls of the steam-cylinder is conveyed to the condenser by convection.

Radiation.—Steam-pipes radiate heat into the surrounding atmosphere or the enclosing walls. How can this loss be prevented? By clothing the hot surfaces with non-radiating substances, as already mentioned. It is highly probable that the characteristic of non-radiation is due to the presence of confined air among the interstices of the substance or material; as air is a bad conductor of heat, and offers a barrier to the escape of caloric.

Special Notice of Materials.

Cast-iron is used for such parts of an engine as require a great degree of rigidity or stiffness—as the foundation-plate, the cylinder, cylinder-cover, steam-chest, condenser, piston, junk-ring, columns, plummer-blocks, wall-boxes, and the fly-wheel.

The fittings of the boiler consume a small portion of cast-iron—as the furnace-front, the dead-plate, the fire-bars, stop-valves, and steam-pipes.

Wrought-iron is used chiefly for those parts which are subjected to great strains or sudden shocks, and also for the parts of the engine which are in motion—as the piston-rod, connecting-rod, crank, crank-shaft, excentric-rods, excentric-hoops, cross-heads, and parallel-motion. The boiler is constructed entirely of wrought-iron.

Steel is coming largely into use, and it is, in many cases, taking the place of wrought-iron, without interfering with the use of cast-iron. Many absurd objections against steel have been withdrawn since it has

been proved by important experiments not to be so treacherous as some persons have tried to make out. The use of steel for *boiler-making* is greatly on the increase. The increase is due to the material being produced of such a mild quality as to warrant its introduction into the boiler yard, and to be perfectly adapted for the construction of steam-boilers. Steel is largely used for bushes, to reduce the wear and tear; likewise for crank-pins, parallel-motions, and links.

Copper is mostly used alloyed with tin, to form a hard metal—gun-metal. It is used for forming the bearings for supporting the crank-shaft, the beam, and other revolving pieces. The big-end and the little-end of the connecting-rod are lined with it.

Brass is also an alloy of copper with zinc. It is comparatively soft, and is used for mountings only.

White-metal is used and applied as a lining to gun-metal bearings on account of its anti-frictional property. Sometimes it is used for the whole bearing, but the journal bedded entirely in white-metal cannot be allowed to revolve without oil for many minutes, because the metal is liable to melt at a very moderate temperature. On the contrary, if it is well used and properly lubricated with oil, for small shafting running at a high speed, it is more serviceable than gun-metal for bearings.

Muntz-metal is used for bolts and studs to resist the action of steam and grease. It is usefully employed inside steam-chests and under water, as it is not liable to be corroded, or otherwise affected by salt-water.

The whole of the metals of which the engine and the boiler are composed are full of interest. They are distinguished differently—some for their lustre,

ductility, malleability, and tenacity; others are elastic. Some metals combine together in their melted state, whilst there are others whose characters and natures are changed completely when combined with other metals. Metals are all fusible, but they melt at different temperatures. An alloy or mixture of metals sometimes destroys the malleability and ductility possessed by either metal singly.

Friction.

The principal causes of friction are the roughness of the rubbing surfaces, bad workmanship, and the equality of the asperities of two surfaces. A bearing may be turned ever so nicely and smoothly; still it is rough. It appears smooth to the eye, which cannot perceive the pores in the surface; and if, with good workmanship, the bearing is still rough, requiring oil to get it to work with ease, we may be sure that bad workmanship is expensive workmanship. The same may be said of a smooth bearing, if we ignore the fact that some substances *are* smoother than others, and some *are* harder than others. The degree of friction of two bodies in contact, depends upon the pressure of the one on the other, and is nearly independent of the area of the surfaces in contact. It depends on the nature of the materials in contact, and on the nature of the lubricant, as oil, or tallow.

Friction does not materially increase with the extent of the rubbing surface, and, therefore, it is an obvious advantage that the bearing surfaces of steam engines should be as large as possible. There is a great increase in the durability. In fact, ordinarily, less power is required to drive a shaft having a long

bearing than one having a short bearing, since the surface being large, the pressure is not so great per square inch, and, therefore, it is lubricated better, and thus the gain from reduction of the friction is greater than the loss attributable to the increase of the diameter of the bearing.

The size of the bearings, then, should be a matter for consideration beyond, or besides, that required to obviate a break-down. The pressure or weight on the shafting should be distributed over a surface of sufficient extent, so that the pressure per square inch may be reduced as much as possible, and the resistance due to friction reduced, enabling the oil to cover the bearing well, and at the same time maintaining the bearing at a low temperature and preventing the oil from being carried off by heat.

Whilst friction does not materially increase with the velocity of the rubbing surfaces, it increases in amount as the velocity per unit of time during which the friction is excited. Thus, the friction for each stroke of a piston is the same, whether it makes 20 strokes or 40 per minute, but in the latter case there are twice the number of strokes; and, therefore, the friction per stroke is the same, but the resistance of friction per minute is doubled.

The term "co-efficient of friction" signifies the proportion which the resistance to sliding motion has to the force which presses the surfaces together, or, in other words, it is a certain fraction which when multiplied by the normal pressure gives the friction. Thus a smooth, clean, and dry brass plate, loaded with 100 lbs. will require a force of 22 lbs. to slide it over a cast-iron one in a similar condition, and that is

twenty-two one-hundredths of the weight; and the co-efficient of friction is ·22. With any other weight or pressure on the plate we could determine the force required to slide it by multiplying the pressure by the co-efficient of friction. Thus, if the plate be loaded with 250 lbs., the force required to move the plate would be 250 × ·22, which product is 44 lbs. The co-efficient of friction varies for different materials. It is 0·22 for brass and cast-iron, while it is 0·15 between cast-iron and cast-iron, and between two pieces of wood about 0·4. These co-efficients apply to clean, dry surfaces. The amount of friction is considerably reduced by lubricants, and by the manner in which they are applied.

It has been proved that when a bearing is but slightly greased it is no better than when dry; but when it is properly oiled the co-efficient of friction is reduced as low as 0·025. Between ·22 and ·025 there may be any degree of frictional resistance according to the condition of the bearing and the lubrication. For the purpose of calculation the co-efficient of friction is generally taken as ·07.

There is another point worth mentioning, and that is, that under varying conditions different lubricants are required, as pressure has a tendency to press out the lubricant, and then the amount of friction depends more upon the nature of the unguent than upon that of the surfaces in contact. Up to a certain pressure per square inch, mineral oil may be used with good results, as it contains no vegetable matter and keeps the bearing clean. In fact, mineral or rock-oil is extensively used, and by its volatile nature it assists in carrying the heat away. Unlike many of the fixed

oils, it does not leave a resinous matter behind it; but it is easily evaporated by heat, and takes fire at a much lower temperature than animal oil or vegetable oil. Still, it is capable of good service. Equal parts of pure lard oil and paraffin make an excellent lubricant. Lard oil is sometimes adulterated with cotton-seed oil —a cheap oil, and one almost worthless for either lubrication or burning in a lamp.

Grease or tallow mixed with oil is the only substance that will suit very heavy bearings, and in some instances grease and plumbago will prove very effective in reducing friction and getting a bearing round to itself again; or, it can be used regularly. A very small portion of plumbago—just a pinch or two per day—will fill up the holes in the bearings and produce a very smooth surface. Grease for cylinders should be replaced by good oil. Impure grease or tallow found, often in black pieces, in the cylinder, is very destructive to the engine.

SYPHON.

A syphon consists of a number of worsted threads through which the oil rises to some height above the level in the oil-cup, and then descends to the journal. When these threads are crowded into a syphon pipe they cannot work properly. Again, they cannot pass solids, and, therefore, they are useless for tallow when in a congealed state. Once more, the syphon ought to extend so far down the tube that its extreme end is below the bottom of the oil in the cup.

CHAPTER III.

THE STATIONARY ENGINE—CONDENSING BEAM ENGINE.

PLATE I.—A is the cylinder, securely bolted to the base-frame J 2, placed inside the outer casing or steam-jacket B 2.

B is the valve or nozzle; C the cylindrical slide-valve, by which the admission of steam to the cylinder is regulated, as well as the exhaust to the condenser. A 1 is the upper steam-port; A 2 is the lower steam-port; B 1 is the throttle-valve in the steam-pipe. It is here shown in the position it occupies for convenience; but it is usually placed close to the nozzle. D is the piston, to which the piston-rod E is attached by means of the conically formed end, and the nut E 1. The piston-rod passes through the stuffing-box A 3, and the upper end is fixed to the middle cross-head E 2. F, the main-links of the parallel-motion connecting the cross-head to the cylinder-gudgeon at the end of the working-beam or main-lever G. The parallel-motion consists of the main-links F, the back-links F 1, the parallel-rods F 2, and the radius-rods F 3. There is a complete set of this motion on each side of the main-lever or beam. The parallel-rods connect the cross-

head E 2 at the lower ends of the main-links, to the cross-head F 4 at the lower ends of the back-links.

The radius-rods connect the cross-heads at the lower ends of the back-links, to the studs or pivots H 2.

H is the spring-beam to which the brackets supporting the studs are secured. The upper end of the air-pump-rod Q 1 is fixed to the middle cross-head Q 2. The back-links connect this cross-head to the gudgeon Q 3, fixed in the main-lever.

The function of the parallel-motion is to keep the piston-rod and the air-pump-rod in direct vertical lines of ascent and descent, thus preventing the side strains which would, if they were not so supported, act upon them when at work, arising from the curvilinear motion of the end of the beam.

The centre or main gudgeon G 1, on which the main-lever oscillates, is supported by bearings or "plummer-blocks," one on each side of the main-lever. These are bolted to the spring-beam and to the entablature J, beneath the spring-beams. The entablature supports the spring-beam under the main-gudgeon. The ends of the spring-beam are secured to the cross-girders H 1. The extremities of these girders, and of the entablature, are built into the walls of the engine-house.

The entablature is further supported by the columns J 1, one under each main plummer-block.

The upper ends of the columns are firmly fixed to the entablature; and the lower ends to the base-frame J 2. The base-frame is secured by holding-down-bolts to the foundation.

The gudgeon at the other end, G 3, of the main-lever, is connected by the connecting-rod K to the crank-pin K 1, fixed in the end of the crank K 2.

The crank-shaft L, to the end of which the crank is firmly keyed, is supported by and revolves in the bearing L 1, bolted to the base-frame.

The fly-wheel L 2, and the excentric M—shown on the drawing in dotted lines—are likewise keyed to the crank-shaft M 1. The excentric-rod connects the excentric to the lever M 2. Levers, N 1, are placed on the same shaft, at right angles to the lever M 2, one on each side of the slide-case.

N the rocking-shaft or weigh-shaft, on which the levers N 1 and M 2 are keyed.

The side-links C 3 connect the ends of the levers N, 1, to the cross-bar C 2, on the slide-spindle.

The slide-valve rod or link, C 1, is fixed at the lower end to this cross-bar, and at the upper end to the slide-valve.

N 2 is the balance-weight, fixed on the back end of the lever N 1, to balance the weight of the slide-valve and the rods. O 1 is the exhaust-pipe leading to the condenser O. O 2 is the injection-sluice, by which the injection-water for condensing the steam is admitted, as a jet, and the amount regulated. O 3 is the passage from the condenser to the air-pump P. P 1 are the suction-valves; P 2 the delivery-valves; Q the air-pump-bucket, provided with valves. Q 1 the air-pump-rod, fixed at the lower end to the bucket, and at the upper end to the middle of the cross-head Q 2, as already mentioned. R is the hot-well; S the cold-water cistern, in which the condenser and the air-pump stand, surrounded by water. S 1 the overflow-pipe for waste water. T is the cold water pump; T 1 the suction-valve; and U the pump-bucket, also supplied with a valve. V the rod connecting the bucket

to the gudgeon V 2, fixed in the main-lever; T 2 the delivery-pipe to the cold-water cistern. V the feed-pump; W, the plunger, connected to the gudgeon W 2 in the main-lever by the rod W 1. V 1 is the suction-pipe from the hot-well. V 2 the delivery-pipe to boilers. X the standard supporting the governor. X 1 is the governor-spindle, on the lower end of which is keyed a bevil-pinion worked by a bevil-wheel fixed on the shaft; X 2 is the fulcrum at the upper end of the spindle for the arms or bell-crank levers X 3. The governor-balls X 4 are fixed to the extremities of the lower arms. The ends of the upper arms are connected by the links Y 1 to the sliding-brass Y. The rod Y 3 is attached at the lower end to the sliding-brass by the swivel-joint Y 2; and is connected at the upper end to the bell-crank lever Z.

The rod Z 2 connects the lower arms of the bell-crank levers Z and Z 1. The other arm of the bell-crank lever Z 1 is connected by the rod Z 3 to the end of a lever fixed on the throttle-valve spindle. To this spindle the throttle-valve B 1 is also fixed.

The working of the engine is as follows:—To start the engine, the first operation is to get rid of all the air and water in the cylinder and steam-passages, and to warm the cylinder by admitting steam to the jacket B 2. This is effected by blowing through a quantity of steam into the condenser. The steam is condensed and a vacuum is produced at one side of the piston; whilst steam is admitted to the other side.

These operations are carried out by working the hand-lever M 3, fitted to the lever M 2 on the weigh-shaft; the excentric-rod M 1 being meanwhile disconnected. The slide-valve is then moved alternately up

and down, in order to distribute the steam to the upper side and the under side of the piston. By this operation the engine is set in motion. The end of the excentric-rod M 1 is then thrown into gear by connecting it to the lever M 2 by hand. The slide-valve is kept in motion by the excentric M on the crank-shaft. The excentric is a circular disc, so formed and placed on the crank-shaft, that the centre of the disc is at a given distance from the centre of the shaft, and revolves about it. The periphery, or outer edge of the excentric, is grooved, and the excentric-rod is connected to it by means of a ring or excentric-strap, as it is termed, fitting into the groove. The excentric-strap is made in halves, bolted together; one half being secured to the excentric-rod.

By this arrangement the strap is easily placed upon, and maintained on, the excentric; and whilst it embraces the excentric, it admits of the excentric revolving within it.

The result of this combination is that, whilst the excentric revolves with the shaft, a reciprocal lateral motion is imparted to the excentric-rod, and to the end of the lever M 2 to which it is connected, the extent of the reciprocating movement being equal to double the distance between the centre of the crank-shaft and that of the excentric. This distance apart of the centres is termed the throw of the excentric.

As the levers M 2 and N 1 are of equal lengths, and both are keyed to the weigh-shaft, the end of lever N 1 moves through a space equal to that traversed by M 2.

The same motion is transmitted through the links C 3, and the slide-valve-rods to the slide-valve.

The shaft, in continual rotation, causes also the

excentric to revolve; and the horizontal movement of the excentric is communicated to the excentric-rod, which in its turn, by means of the levers and rods, imparts a reciprocating movement, though in a different direction, to the slide-valve; the extent of movement communicated to the valve being equal to the whole traverse of the excentric, or to twice the throw. These preliminaries being understood, the movements and working of the engine may now be considered.

Starting the Engine.—Let the engine be in the position where the piston has described one-fourth of its descending stroke. By the mechanism just explained, the slide-valve is placed in such a position that the upper steam-port is left open to the steam from the boilers, which enters through the throttle-valve and the slide-case to the cylinder, and forces the piston downwards.

The lower steam-port is open to the exhaust, and the steam which was admitted to the lower end of the cylinder, and by which the previous up-stroke was made, has passed out and down the exhaust or eduction-pipe to the condenser. There it meets the jet of injection-water supplied from the cistern.

The water is forced into the condenser through the injection-pipe and sluices by the pressure of the atmosphere. The steam, as it comes into contact with the cold water, is instantly condensed, and a vacuum is formed in the condenser, and in the cylinder below the piston. The water employed for condensing the steam, and the condensed steam itself, occupies the lower part of the condenser, until it is pumped out by the air-pump.

The steam is prevented from leaking past the piston

by the packing-ring D 1, which is kept in its place by the ring D 2 secured to the piston. The packing-ring is forced out against the cylinder by means of springs fitted in the space within the piston, at the back of the spring.

As the piston and its rod descend, the end G 2 of the main-lever is also depressed, and at the same time the air-pump bucket is forced down by means of the air-pump rod.

The water occupying the lower part of the pump, which by the previous up-stroke had been drawn from the condenser, is prevented from returning by the valves P 1, which are now closed. As the bucket descends into the water the bucket-valves, which open upwards, allow the water to pass to the upper side; when the bucket arrives at the bottom of the stroke the valves are closed, and they prevent the return of the water to the lower part of the pump.

As the main-lever oscillates on the centre G 1, the depression of the end G 2 causes the opposite end to rise; and by means of the connecting-rod the crank K 2 is pulled up towards the highest point of its revolution.

The bucket of the cold-water pump is also being raised by the rod connecting it to the gudgeon V 2, delivering the water above the bucket into the cold-water cistern, through the pipe T 2.

The water is, at the same time, drawn into the pump through the suction-pipe and the open suction-valve T 1. When the bucket reaches the top of its stroke, the valve T 1 closes.

At the same time the feed-pump-plunger is raised by the rod connecting it to the gudgeon W 2.

The delivery-valve w 4 is closed, and the water is drawn in from the hot-well, through the suction-pipe and open suction-valve w 3. This valve will also close when the plunger reaches the top of its stroke. As the piston nears the bottom of the down-stroke in the cylinder, the altered position of the slide-valve opens the upper part to the exhaust. The steam immediately rushes out of the cylinder, and down the middle of the slide-valve and exhaust-pipe, to the condenser, where, meeting as before the injection-water, it is condensed —forming a vacuum in communication with the upper side of the piston. By the continued movement of the slide-valve, it gradually opens the lower part to the steam from the boiler, and enters the cylinder under the piston. The piston is then forced upwards.

The end G 2 of the main-lever is also forced up, and with it the air-pump bucket is raised.

Air and water are thus drawn from the condenser through the suction-valves into the air-pump, and they are prevented from returning by the closing of the valves.

The water above the bucket is forced through the delivery-valves P 2 to the hot-well. The supply of feed water for the boilers is drawn from the hot-well by the feed-pump.

The waste water overflows through the waste-pipe R 1. The end G 3 of the main-lever is now depressed, and with it also the cold-water pump-bucket, and feed-pump plunger.

The suction-valve of the cold-water pump being now closed, as the bucket descends, the water in the pump passes through the bucket-valve to the upper side, ready to be delivered to the cistern by the next up-

stroke. The suction-valve of the feed-pump also being closed, the descending plunger forces the water now in the pump through the delivery-valve to the air-vessel V 3, whence it is conducted through the delivery-pipe to the boilers.

The use of the air-vessel is to form a cushion of air, the elasticity of which prevents or modifies the sudden impulses or shocks which would otherwise be given to the pump and its parts by the inelastic movements of water, which is incompressible.

The depression of the end G 3 of the main-lever causes the depression of the connecting-rod, forcing down the crank-pin towards its lowest point.

By the movement of the engine, the position of the slide-valve is again changed; and, as the piston nears the upper end of the up-stroke, the lower steam-port is again opened to the exhaust, and the steam passes to the condenser, as before. The upper steam-port is then opened to the steam from the boilers, and the piston is again forced down.

For each revolution of the crank-shaft there are two positions of the crank, called the dead points, at which the power of the engine exerted through the connecting-rod has no influence in causing revolving motion.

The dead points are those at which the crank-pin is at the highest and lowest positions of its revolution (1 and 2, Fig. 1, page 46).

When the crank is at the highest and lowest positions, the force of the steam on the piston is exerted in simply pulling or pushing the crank-shaft upwards or downwards.

To compensate for this characteristic of the action

of a crank, the fly-wheel, which is keyed to the crank-shaft, comes into play. By the momentum acquired by the fly-wheel during the intermediate portions of each revolution, when the crank is taking up the power of the engine, the crank is carried past the dead points; and thus from the up-and-down motion of the connecting-rod the continuous circular motion of the crank is obtained, and the shaft is made to rotate.

By the momentum of the fly-wheel also the engine is caused to work more equally and more smoothly than it could possibly work without such co-operation.

The use of the governor is to maintain the engine at a regular speed, and to proportion the quantity of steam used to the work which is to be performed.

The principle of centrifugal force is here applied. When the engine goes too fast, the rapid rotation of the shaft is communicated to the spindle of the governor and to the balls by means of the bevil-gearing.

The centrifugal force thus generated causes the balls to fly outwards and the upper arms or levers to rise. The brass-slide Y is thus forced up, and the movement is transmitted through the rods and bell-crank levers (as indicated in the drawing) to the throttle-valve, by which it is partly closed.

The quantity of steam admitted being thus reduced, the too rapid speed of the engine is checked and reduced. Conversely, if the engine is moving more slowly than when at its regular speed, the velocity of the governor is lessened and the balls fall. By the fall of the balls the brass-slide is pulled down and the throttle-valve is farther opened; more steam is thus

admitted to the engine, and its speed is brought the proper rate.

Steam is not admitted into the cylinder durin whole of the stroke of the piston; on the contrar slide-valve is closed, and the supply of steam is c to the cylinder before the stroke of the piston is pleted. The enclosed body of steam expands a piston moves on to the end of the stroke, and fill cylinder. But the pressure of the expanding decreases as the space into which it expands incre

This is the principle of the expansive-worki steam-engines. The practice of expansive-wo to a greater or less degree is universal, and i means of effecting economy of fuel to a consid extent.

Though the maximum available power of an e may be reduced by the practice of expansive- ing, yet, on the other hand, if steam from the were to follow the piston right to the end c stroke, the engine would not pass the dead poi smoothly as when it is cut off short of the end c stroke; and, besides, the exhaust-passage wou come choked with steam, and the final result be a considerable increase of back-pressure.

Thus, if the steam is cut off at one-third stroke, the remaining two-thirds of the cylinder is reserved for the expansion of the steam lod the first third part.

It is found in practice that steam is saved in g proportion than the power is reduced. Hen economy of the principle.

A certain quantity of power is really gained, will be evident on consideration that althoug

Plate 1.

pressure by which the piston is impelled by steam worked expansively is gradually decreased as the volume of the steam in the cylinder increases, all the power given out by expansive action is obtained without the expenditure of any additional steam, and without any additional expenditure of fuel. On the expansive principle, steam of a higher pressure is used than is ordinarily the case in condensing steam-engines, where a low degree of expansion only is carried out.

CHAPTER IV.

DETAILS OF THE STATIONARY ENGINE.—CONDENSING BEAM ENGINE.

ALTHOUGH the "key" to the engine embraces as a ready reference a general view of its parts, yet only a cursory knowledge of the details can be obtained from it. The practical information which the engineman seeks can only be given by another process—namely, by applying to each detail a due amount of explanation, so as to give the why and the wherefore of each.

While it may be sufficient for one man to know that the steam is let into the cylinder by the slide-valve, another requires to know the benefits of lap and lead—the properties of the slide-valve. One man may be satisfied with nothing short of knowing how to test valves, and in fact not satisfied at all until he can see *through* the engine as plain as he can see his face in a glass.

Crank, K 2. (Plate I.).—If claims to the glory of first suggestions or of original invention are to be rigorously insisted upon, then the name of Jonathan Hulls must be made mention of. The crank motion, of which he was the patentee, is alone sufficient to immortalise his name amongst mechanics. A considerable time elapsed after the invention of the engine before a crank was em-

ployed to produce a rotatory movement from the reciprocating action of the engine beam. It is a remarkable fact that whilst much talent and ingenuity were being employed to find out a plan which should convert a rectilinear motion into a circular motion, and so utilise the engine for driving machinery as well as for pumping water, the means were nigh at hand, even in the street, to be seen in the knife-grinder's wheel. But where a rotatory motion is to be obtained from a reciprocating one, by means of the crank, a fly-wheel, L 2, is necessary to continue the motion at those two points of the revolution, called the dead points, in which the crank lies in the direction in which the moving force acts, for at the dead points the crank affords no leverage to the power, and consequently no power can be effectively exerted. When a force is alternately applied suddenly to a body, and ceases to act, it is an intermittent force. Such is the nature of the action of the steam on a crank through the connecting-rod which ceases to impel the crank at the dead points. With the aid of a fly-wheel on the crank-shaft, after a few revolutions momemtum is acquired sufficient to carry the crank past the dead centres, and to urge it forward in the direction of its circular motion until it is brought into a position again to offer leverage for the steam acting through the connecting-rod. When steam is urging the piston it is urging the crank; when its power ceases on the piston it ceases on the crank, and the augmentations and the diminutions of the power thus exerted, which follow each other rapidly, are by the momentum of the fly-wheel as a reservoir of force, converted into equable and regular action. But at every revolution of the crank

and fly-wheel, the heavy piston and the massive beam with its appendages have to be twice reversed in their motion; and were these reversals to be suddenly effected the engine-house would soon come down.

The shock at the reversal of the motion is prevented by means of the crank. Let *a b*, Fig. 1, represent the crank, equal to half the length of the piston stroke 1 2, or half *d f*, and let *d c a c f* represent the semicircle through which the crank travels whilst the piston performs a stroke, 1 to 2; then, with lines drawn from the stroke line to the crank-path line, it will be seen that the piston travels from *b* to *g* nearly at the same speed as the crank, and in the same time as the crank travels from *a* to *c*. But let us regard the next and finishing part of the performance: whilst the crank moves through the space *c* to *d*, the piston moves from *g* to *d*, only half the distance, and therefore at half the speed, and so the piston is checked and slowered in its speed as it nears the ends of the cylinders, and the shock which otherwise would have occurred is avoided.

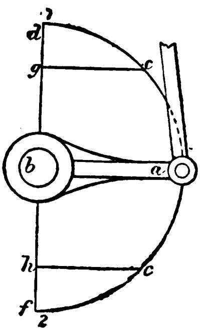


Fig. 1.

Link-motion.—The link motion is not fitted to all engines, as in some cases it would be superfluous, and would only increase the number of working parts of the engine. Any saving of fuel that might be effected by it would not atone for the expense of making it and keeping it in order.

The principle of expansion can be attained, with sufficient economical results in some cases, *by means of*

the lap on the slide-valve, independently of a separate expansion-valve, which is sometimes used to cut the steam off at any required portion of the stroke.

Therefore the link-motion is not absolutely required to obtain expansion. Some young enginemen are apt to think if an engine is without the "link" it is working without expanding the steam. It is not so. The steam is generally, in engines not fitted with the link, cut off at one-third of the stroke by means of the lap. Practical considerations form the best guide as to the "cut-off," but in cases where the load upon the piston is uniform, there is no reason why the cut-off should not be uniform also. The same argument would not apply to an engine whose piston worked under varying loads, especially where expeditious starting was required, and varying loads and speeds were involved. Then the expansion gear is employed with fine effect, as the steam can be allowed to follow the piston to nearly the end of the stroke, to get the speed up quickly, or it can be cut-off at one-eighth of the stroke.

The link-motion is also employed for the purpose of reversing engines. It consists of two excentrics, with their respective rods attached to the curved link, which is frequently formed to a radius equal to the length of the rods.

The link is made open; a "die" block, which is in connection with the valve, may be made to traverse it by shifting *the link*. The horizontal motion of the link is communicated to the valve by the joint action of the excentrics. When the die is in the centre of the link, the travel of the valve is reduced to a minimum, being equal to twice the linear advance of the excentric. One

excentric moves the top of the link one way, whilst the other excentric moves it the other way, so that the reciprocating motion at the centre is just as much one way as the other, and if steam were turned on it would have no effect in moving the engine when the valve has not sufficient travel to uncover the ports. But by lowering the link the amount of travel is increased; and, when the link is lowered to the full extent, the valve receives its maximum travel; the excentric-rod occupying a position as nearly as practicable in a straight line with the valve-spindle. Thus the amount of travel which is communicated to the valve depends upon the distance at which the movable block may be from the central point in the link. By moving the "die" up and down in the link—which is, in effect, the same as the lowering or raising of the link on the die—the amount of travel of the valve may be varied; and seeing that the travel of the valve is the measure of the lap, to reduce the travel by raising the link is equivalent to increasing the lap, and hence it is that the link-motion derives its advantage in being able to regulate the amount of expansion, so that the steam can be measured out to suit the load upon the piston.

Parallel-motion, F.—The object of the parallel-motion is to provide for the rectilinear motion of the piston-rod, and to counteract the oblique push from the end of the beam. As the beam in all beam engines vibrates upon a centre, the end of it describes a portion of a circle over the piston-rod. The piston-rod, on the contrary, is bound to move up and down in a right line; it cannot, therefore, be directly attached to the end of the beam, and hence the intervention of the elegant mechanism called the parallel-motion, by means

of which the alternating rectilinear motion of a piston is made to work harmoniously with the alternating curvilinear motion of a rocking beam. The motion consists of the main-links F, the back-links F 1, the parallel-rods F 2, and the radius-rods F 3. The parallel-rods connect the cross-head E 2 at the lower ends of the main-links to the cross-head F 4 at the lower ends of the back-links. The radius-rods connect the cross-head at the lower ends of the back-links to the studs or centres H 2 on brackets by the sides of the piston-rod.

The principle of the motion is briefly this: The motion of the end of the parallel-rod F 2 is so confined by the motion of the end of the radius-rod to the point E 2 as to cause it to describe a right line. By doing so it maintains the alternating rectilinear motion of the piston in the same path.

Governor.—The application of this fine piece of mechanism for governing the supply of steam to the cylinder was made by Watt. The governor was not invented by him: in his day it was in use in many corn-mills, which, from the days of the Romans, have been the nursery of engineering skill, invention, and superior millwrighting. The great man saw it regulating the speed of the stones so that their centrifugal force should not exceed the centripetal force, and the brilliant thought occurred to him that it could be used for governing the speed of the steam-engine: a very desirable object to be effected, since engines are liable to "race," with the contingency of breaking themselves to pieces. It is not by any means a rare occurrence for a fly-wheel, or a part of a fly-wheel, to break through the wall of an engine-house in consequence of

the engine not being well under the control of the governor. All forces act in right lines, and when a mass of iron is moving in a circle it has a tendency to fly off in a right line, forming a tangent to the circle of motion. This tendency may be simply exemplified by whirling round a can of water or a weight by means of a string. As the speed of revolution is accelerated it is found necessary to hold the string more and more tightly. Now the force which pulls the string is the centrifugal force, and when this force is alarmingly increased, in the case of an engine running off too fast, the danger is that the fly-wheel will burst and fly to pieces, the centripetal force due to the cohesion of the metal keeping it together having been exceeded by the centrifugal foree. Now the engine governor is specially adapted to keep the speed below such a dangerous point. When the engine is in motion, the motion of the shaft, on which the fly-wheel is keyed, is communicated to the governor-spindle X 1, at the lower end of which is a bevil-pinion worked by a bevil-wheel fixed on the shaft.

The centrifugal force thus generated in the governor-balls causes them to fly outwards and the levers to rise. The brass-slider Y is forced upwards, and the connecting-links Y 1 brought downwards.

This vertical movement is transmitted, through the rods Y 3, which are lowered, to the bell-crank lever Z; and thence through the rod Z 2, by which the lower arms of the bell-crank lever are connected to Z 1, the other arm of the bell-crank lever. Z 1 is connected by the rod Z 3 to the end of a lever fixed on the throttle-valve-spindle, and to this spindle is attached the throttle-valve B 1, which is open when the engine is at

rest, and the opening of which is reduced as the speed is increased. When the speed becomes greater than the regulated speed the governor-balls fly outwards, and in the manner just described steam is partly cut off and the speed reduced.

Piston, D.—There is no part of a steam-engine which requires to be more truly and accurately fitted than the piston. It consists generally of a hollow disc of cast-iron—strongly ribbed in large engines—with a tapered hole in the centre, which fits the corresponding conical end of the piston-rod. The rod is secured to the piston by means of a strong brass nut and a check-plate.

The piston-rod is readily removed by undoing the check-plate and unscrewing the brass nut whilst the piston is warm, when it easily leaves its conical seat in the piston. The outside of the piston is turned to fit the cylinder so that it will work up and down without binding anywhere and without being slack. If it does not touch the cylinder at every part when the steam is admitted on one side of it, the steam will blow through and will react on the other side of the piston, so neutralising a part of the force on the first face. If the piston were to fit the cylinder too tightly it would rub hard against the sides of the cylinder, and the friction thus set up would soon cause it to become too slack. Steam would then blow by between the cylinder and the piston, or between the rubbing surfaces. The pistons of themselves could not be made to retain the requisite tightness for any length of time. For this reason, special provision is made for packing the piston. Around the outside of the piston a recess, or a series of recesses, are turned out

to receive a steel spring, immediately outside of which is fitted a cast-iron ring, which is turned and finished a little greater in diameter than the cylinder, so that when a piece is cut out with a saw and the space closed by compressing the ring, it will then fit the cylinder accurately and not too tightly. Its tendency to spring out causes it to press against the sides of the cylinder, and thus it is that an elastic metallic ring prevents the steam blowing past the piston. This metallic ring is kept in its place by means of a junk ring applied to the outer face of the piston, and fastened by screws to the body of the piston, so adjusted as to allow the metallic ring freedom to work round in the recess, and force itself outward in all positions of the piston. If the junk ring happen to be screwed down so as to jam the metallic ring, then the steel spring underneath it is prevented from exercising its function of assisting to keep the metallic ring in uniform contact with the barrel of the cylinder.

Air-vessel, v 3.—This vessel is fitted on the delivery-pipe or the upper side of the pump-valve boxes. It is a contrivance for continuing the flow of water when the impelling force of the ram has ceased to act, or whilst the pump-ram is making the outdoor stroke. It thus keeps the discharge more nearly constant than it would be without the air-vessel. It also prevents the shocks which would arise from the sudden stoppage of the water whilst in motion, and obviates the loss of power which would be involved in stopping and starting the water from a state of rest at each stroke. With a single-acting pump, imagine that the discharge of water into the delivery-pipe is faster than it

can escape through the delivery-valve, the water rises in the air-vessel which contains air, and the air is compressed proportionately to the pressure concentrated upon the water. On the return-stroke of the ram, as it makes the outdoor stroke, the valve above the pump closing, the compressed air in the upper part of the air-vessel expands and reacts on the water inside of it, and continues to expel the water until the pressure of the air becomes equal to the back-pressure of the column of water between the air-vessel and the mouth of the delivery-pipe. The air acts, therefore, as a sort of elastic cushion in the air-vessel, and neutralises irregularities in the working of the pump. The pump works all the better with an air-vessel; the air-vessel takes the knock off the pump. The knock takes place when the ram makes the suction-stroke, and the water in the delivery-pipe falls back suddenly upon the valve or clack, forcing it down upon its seat with a rattle. But, as already explained, the knock is obviated by the action of the expanding air, which keeps the water back and continues it in motion towards the boiler. In large pumping-engines, supplying water in great quantities or at great pressures, it is found imperative to form a reservoir of air in the air-vessel to counteract the irregularities which take place in the mains. A special pump is, in fact, employed to pump air into the air-vessel, so that, by means of the elastic power of the compressed air, which is limited by self-acting valves of the ordinary lever safety-valve kind, the shocks and irregular actions which are set up in the mains are counteracted.

Valve-motion.—One of the earliest and simplest contrivances for reversing the course of the passage of

steam into the engine was a four-way cock, which was used by Leupold a hundred years ago, but was invented by Papin many years before that time.

But it may be well to mention that, two hundred years ago, the piston was reversed by withdrawing the fire, when the steam was condensed by cooling the cylinder by the air from the outside. In the next stage of improvement the fire was retained, and the cooling of the cylinder, and the consequent condensation of steam, was effected by dashing cold water over the cylinder.

It appears very strange that our ancestors should have contrived to raise a piston and not at the same time discovered how to lower it with equal facility.

Following the plan of condensing the steam after it had lifted the piston to the top of the cylinder by cooling from the outside, means were used to cool the cylinder within by opening a cock and flooding the cylinder with water from a tank fixed above, so that the water could enter by the force of gravity. The steam having been condensed, and the contents of the cylinder run off, a vacuum was formed and, the top of the cylinder being open to the air, the pressure of the atmosphere on the face of the exposed piston lowered it to the bottom of the cylinder, and at the same time lifted a bucket full of water from the mine. The steam was again admitted by a *cock* to raise the piston, and by the same movement the empty bucket was lowered into the water. Thus, the lifting of the water, which was the work done, was not performed by steam, but, as already explained, by the atmospheric pressure, which pressed the piston into a vacuum beneath it. Hence it is that such engines were called atmospheric

engines. The pressure of the atmosphere is $14\frac{3}{4}$ lbs. per square inch, and with a piston having an area of 100 square inches 1,475 lbs. of water could be lifted from the mine to a height equal to the length of the cylinder. The elastic force of the steam was the first power, and the atmospheric pressure was the second power. The operation of working such an engine required constant attendance. If steam was admitted to the cylinder too long, the piston was sent out of doors into the fields; and if it was allowed to descend with its whole force to the bottom of the cylinder the chances were that the engineman would find himself up to his neck in scrap-iron.

The management, therefore, required constant supervision with sprightly action to make a fair number of strokes per hour. A fair day's work was done when fourteen strokes were made per minute.

This necessarily wearisome and constant watching of the piston became distasteful to a young engineman named Humphrey Potter, a "Staffordshire knot," and he concocted a catch applicable to the steam-cock, and which was moved by a piece of string attached to the beam, and made the engine comparatively self-acting. Humphrey was quite a lad, and this was done to allow him to do a little business amongst the "birdies," to look for a tomtit's nest in the stump of an old oak, or climb a fir-tree for a hatch of thrice-cocks.

This device of Potter's drew attention to the advantage of making the engine more nearly self-acting, and the incident gave rise to many and useful inventions which have since become incorporated in the valve-motion.

As time advanced, the gear was made up of "tumbling

bobs," "forked-legs," "centre-pins," "shanks," "spanners," "tooth-sectors," "snifting-valves," "valves" moving on a hinge. By manipulating these "crinkum-crankums" the speed of the engine was accelerated.

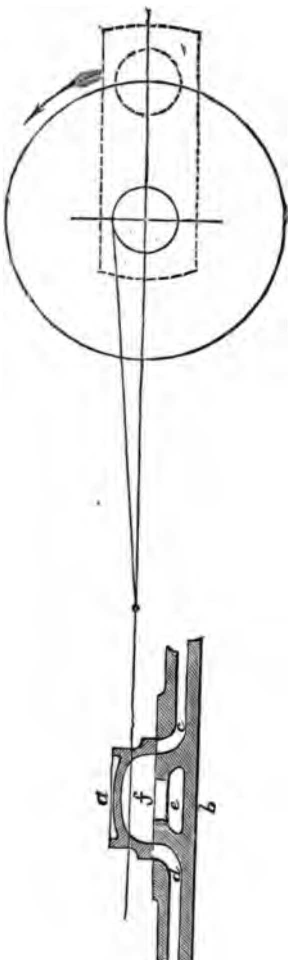


Fig. 2—Old Slide-valve.

The valves for admitting steam to the cylinder were either conical or flat-faced, worked by means of a chain or a catch attached to a lever suspended from the beam.

Later on, Watt worked the valves, which were conical, with tappets on the pump-rod, which, in ascending and descending, caught the lever attached to the valves, and therefore opened and shut them as required.

Murdoch, an assistant of Watt, invented the D-slide-valve and the excentric-gear for working it, illustrated by Fig. 2, which was a great stroke of engineering, and takes precedence in its adoption for general use before all other systems. *a* is the valve, *b* the cylinder, *c* the back-port, *d* the front-port, and *e* the exhaust-port; *f* the cavity of

the valve. It will be seen that the outer edges of this valve just cover the ports leading to the cylinder, and therefore a movement in either direction given to it by the excentric would admit steam into one end of the cylinder. The piston is at the end of the stroke, and the elastic power of the steam when the port is opened forces it down the cylinder. When it arrives at the bottom the opposite port is opened, and the steam, entering at that end, pushes the piston back again to the top; hence the motion of the piston-rod in and out of the cylinder. The valve works backwards and forwards over the ports *a* and *c;* the outer edges of the valve, when drawn towards *f*, let steam into the cylinder; and, when they are drawn from *f*, the ports *a* and *c* are opened to the cavity of the valve, that is, the chamber in the centre of which the letter *f* stands. From this it is clear that the steam-ports *a* and *c* cannot be both open to admit steam for working the piston at the same time; but, by means of this kind of valve, as soon as one port is opened, the other is closed; and, when the port is opened to the cavity of the valve, the steam which pushed the piston to the end of the cylinder can suddenly return, not into the steam-chest, but into the chamber within the valve, and down the port *e*, either into the condenser or the atmosphere. In Fig. 3 the steam-port *d* is shown open to the exhaust-port. The valve is surrounded by steam on the outside, waiting for the valve to move aside and allow it to enter the cylinder; the valve inside is open to the exhaust to allow the steam to leave the cylinder, which it always does when its elasticity is greater than that of the atmosphere. But it will exhaust into a vacuum with an elasticity less than that of the atmosphere,

because a vacuum is emptiness, and the atmosphere is a reservoir of air, having resisting power of itself of $14\frac{3}{4}$ lbs., or as a round number 15 lbs., per square inch. The style of the valve, as given to the world by the ingenious Murdoch, is represented in Fig. 2, and there are, according to the results of modern practice, two defects about it. The first is want of lead, and the second is want of lap.

Fig. 3—Lap-valve.

What is Lead?—Lead is the amount of opening which the valve gives to the steam-port when the piston is at the beginning of a stroke. The opening of the port is given to enable the steam to fill up the steam-port and the clearance at the end of the cylinder, so that it may act as a cushion for the piston in completing a stroke, and to assist in reversing its motion easily, and without straining its connections. When the valve opens the port by $\frac{1}{8}$th of an inch in width before the piston arrives at the end of the cylinder, the valve is said to have $\frac{1}{8}$th of an inch of lead.

What is Lap?—Lap is shown on Fig. 3 at *a a*. This valve represents modern practice. If the pieces of the valve marked off by the line were taken away, it would be the same valve as Fig. 2, and it would just cover the ports in the same way.

Now, if a valve has $\frac{3}{4}$ths of an inch of lead, these pieces, *a a*, are $\frac{3}{4}$ths of an inch in length at each end, back and front, and the valve exceeds the extreme width over the steam-ports by twice $\frac{3}{4}$ths of an inch, or $1\frac{1}{2}$ inches.

After the steam is cut off by the valve, it is locked up in the cylinder until the valve has travelled the amount of its lap, instead of being at once released into the exhaust by the inner edge of the valve; during the period of this travel the steam is pressing on the piston by its expansive force. By means of the link-motion, expansive-working may be either shortened or prolonged; the steam can be expanded more than three times, or it need not be expanded at all. So much for *outside* lap and lead. But there are also inside lap and lead, though not nearly so much as is given outside.

Inside lap is the amount by which each inside edge of the slide-valve covers the steam-port when the valve is at half-stroke. The steam is prevented by it from escaping from the cylinder for a little longer period than when there is not any inside lap, and thus expansive-working is prolonged. But if inside lap is carried too far it may reduce injuriously the time of the release, and cause back-pressure. The engine is then said to be wrapped up.

Inside lead is the amount by which each inside edge of the slide-valve is clear of the edge of the corresponding steam-port; or it is the amount of opening of each steam-port to the exhaust, when the valve is at half-stroke. It has an effect the reverse of that of inside lap, by causing an earlier and freer escape of the steam from the cylinder; but as the steam is not

confined in the cylinder so long, it shortens, as a matter of course, the period of expansion.

Back-pressure is the counter-pressure on the piston at the side opposite to that on which the steam is at work. In a non-condensing engine, it is measured by the amount of pressure above the atmosphere, and may be caused by inside lap and contracted egress for the steam to clear the cylinder. When an engine exhausts into a vat at the bottom the back-pressure is enormous, unless the steam is released by a valve placed on the exhaust-pipe. Back-pressure in a condensing engine is the total amount of pressure on the opposite side of the piston, measured from the line of perfect vacuum. The pressure in the condenser is less than the back-pressure on the piston.

Condenser and its Appendages, o. (Plate I.)—During the dog-days of 1764, the professor of the class for Natural Philosophy of the University of Glasgow placed in the hands of Watt a model steam-engine to repair. What this incident led to would fill volumes to tell. Whilst engaged upon this model, speculation was active in his mind, enthusiasm spread its wings, and these potent influences urged him onwards and onwards, when he became the most enduring character in the history and progress of the steam-engine.

The engine was not the invention of any one individual; it was the outcome of the reflections, the taste, the observations, and the experience of many minds. The rude outline emanated from a brain having the capacity to conceive; its practical adaptation to a workable shape with a capacity to execute. The two faculties are not always co-existent in the same mind, and the palm of victory is carried off by that genius

who elaborates the idea, and applies the principle in such a way as shall demonstrate its power and value. Such a genius was Watt. His means were limited, circumstances contracted his pocket, but he had genius on his side, and he used *that* to smooth the ruggedness of his path. The immortal side of what Watt did may be very briefly given. When the model was in his possession he justly looked upon it as a fair representation of the existing state of steam engineering. He was not an entire stranger to steam or to its action, for he had previously experimented on the force of steam with a Papin's Digester, and therefore his spirit went out to this model and there concentrated the whole of its powers.

Watt saw all its weak points. Although a model, it was an atmospheric engine, in which the cylinder was open at the top to the atmosphere; the condensation of the steam that raised the piston was effected by injecting cold water into the cylinder, under the piston, whilst it was at the top of the cylinder. The very best engines at this period were made exactly on this principle. His acute intellect, unaided by experience in steam to any great extent, noted the prodigious loss of heat from condensation caused by cold water being injected into the cylinder to form a vacuum under the piston. It was mental conception, and not the mechanical faculty, which at this time distinguished his career. The engineers of the day had a perfectly honest admiration for engine-building; his philosophic insight reached beyond. He was blessed with an uncommon share of penetration, and herein lay his strength. Of what benefit would his services have been to the world at large had he simply made larger cylinders of tougher

metal, instead of scattering light where there was no light? He set himself to the task of solving the riddle, by which the engine had been cramped for years; and his strength of resolution rewarded him. Why, at this very time there were men living who had been baptized with steam, but he had divorced himself from the lifeless idea that that had anything to do with the form or direction of *his* life; and his philosophy admirably displayed what could be accomplished by genius.

To his task. *Scene:* A lonely room in the college. *Subject:* Loss of heat from the condensation of steam within the cylinder, by the injection of cold water, to produce a vacuum under the piston. *Note:* The mode of creating a vacuum by the injection of cold water *into* the cylinder itself was suggested by accident, which came about when water was used on the top of the piston to keep it steam-tight, and when the exhaust-steam—that is, the steam which had lifted the piston from the bottom to the top of the cylinder—was condensed by dashing cold water over the outside of the cylinder. A hole in the piston of an engine, through which cold water leaked, so increased the condensation of the steam as to be perceptible; and although at first the improved rate of condensation was not explained, and was attributed to other causes than the right one, yet when the true cause was discovered it engaged attention, and provoked instant action. Simple as it was, it was the means of conferring upon the steam-engine additional interest. It was very easy to inject cold water into the cylinder, and to note its effects, and afterwards compare it with the external splash system. This is exactly what was done, and it

was, as we may now understand, eminently successful, and the operation at once placed the engines that were fitted with an injection-water cock at a premium. Still there was a vast waste of steam, and the engines moved without any appearance of healthy vitality, the action being spasmodic and uncertain. To start the engine, it was necessary to blow steam into the cylinder, and on the lower side of the piston, until they were made as hot as boiling-water. By this operation the heat was extracted from the steam, and taken up by the surfaces of the cylinder and piston. These having become charged with heat—being as hot as the steam—the cylinder was prepared for the opening of the injection-cock. The time for this to be done was known by steam blowing from the cylinder through a snifting-valve attached to it, and which could only happen after the cold surfaces no longer required the heat of the steam to raise them to its own temperature; and when, consequently, the valve was opened by the pressure of the steam, and announced the completion of the operation of heating. The injection-cock was then opened, and the pressure of the column of water in the injection-pipe leading from the tank—which was above—was sufficient to force jets of cold water against the piston, to be afterwards scattered through the cylinder. In a short time the steam was deprived of its heat, and therefore its elasticity; and as it grew colder it extracted the heat from and cooled the surrounding surfaces until a partial vacuum was formed; then the whole pressure of the atmosphere being exerted on the upper surface of the piston, with a vacuum under it, the piston was caused to descend to the bottom of the cylinder. It was raised again by the steam to the top of the cylinder,

and the process of condensing the steam by the injection of cold water was again performed. It may be added that the injection water and condensed steam descended by their own weight through an escape-valve into the hot-well below.

Such was the construction of the engine, and such was the loss of steam in alternately heating and cooling the cylinder to provide a vacuum; and Watt was led to think that he could make a much better engine.

The faults and merits of the engine were alike laid open. There was one thing in his favour, he had the privilege of beginning where his predecessors had to all intents and purposes left off. The engine had already been invented and improved upon by others; and now for the plans and improvements of the immortal Watt, whose name is known and revered throughout the civilised world. His energies were not directed to the employment of steam as a motive-power—his predecessors had done that—but they were concentrated upon its economical use; and herein lay the wisdom of the great man.

The generation of steam in a boiler was not the subject of any man's patent; but its economical employment was such, and it is so now.

To economise heat was the aim of his noble ambition—the subject of his pursuit; and there could be only one result bearing some proportion to his convictions and knowledge of the matter.

It was undeniable that when a quantity of water was heated and cast off steam, and the steam was again reduced to water in order to produce a vacuum, the process involved an expenditure of heat. The fact was patent, but it required a reasoner and demonstrator to

prove that the expenditure of heat in alternately heating and cooling the cylinder was three or four times as much as would have been required to fill the cylinder with steam to work the piston.

Straitened he was for tools, but not for devices, for he went straight to the point. Inserting a glass tube into the spout of a teakettle, he allowed the steam to flow through it into a glass nearly filled with cold water until it boiled. Seizing the glass, he found that the water had only increased a sixth part in volume. That such a comparatively small quantity of water should, when in the form of elastic steam, hold such a quantity of heat struck him with astonishment. Here was something hidden! With a steady persistency and with bright hopes, he bent the whole force of his mind to seize the phenomenon before him, and to shake the truth out of it. No wonder that a small quantity of steam should absolutely surprise him in its transmitting so much heat to cold water; but now he had discovered, hidden in the steam, *latent heat*, which had not been noticed by him before, and was not to be detected by the thermometer. Experimenting further, he came to the conclusion that a pint of water converted into steam would raise six pints of water to its own heat (212°); but that, on the other hand, a pint of boiling water (at 212°) would not do $\frac{1}{6}$th part as much. Where was the heat, then, but hidden in the steam, by which steam at 212° could raise the temperature of a given weight of water six times more than an equal weight of boiling water (212°) would do? The quantity of heat consumed in vaporisation beyond what was required to bring the water to a state of ebullition had been left out of the reckoning; and, instead of the

quantity of heat in the steam being 212°, its total quantity was nearer 1,000°. His experiment was not in vain, for verily it was a brilliant discovery. This doctrine of latent heat was already known to and taught by Dr. Black, who discovered it; but Watt was not in search of latent heat—he stumbled over it; what he required he, however, found, and more, and that was, that before a vacuum could be formed under the piston all the heat, 1,000° or more, which had conferred elasticity on the steam would have to be extracted by cold water by the injection, and that the whole would be wasted.

With this valuable information now in his possession he searched further into the phenomena attending the conversion of water into steam, and he discovered a defect which disposed him to make an alteration in the engine that secured to him immortal fame.

Whilst experimenting, he observed that the injection water thrown into the cylinder to condense the steam became hot, and therefore produced vapour which resisted somewhat the atmospheric pressure upon the upper side of the piston. He jacketed the cylinder with wood and reduced the injection water; but there remained steam or vapour to rob the engine of a proportionate part of the atmospheric motive-pressure. He discussed with himself the desirability of condensing the steam without cooling the cylinder. He was, he knew, doing real work, encouraged to persevere solely out of love for the subject; and, being prompted by the reflection of how well he had so far advanced, he pressed onwards; and, meditating on the fault at issue, he conceived in his gigantic brain the separate *condenser* and the *air-pump*, which brilliant

thought solved the great problem that had perplexed all who had gone before him—the formation of a vacuous space in a hot cylinder; and which also filled the world with the fame of the mighty Scotchman. The separate condenser was a great idea, and the air-pump in conjunction with it was equally as great. These constituted two great steps in advance of all previous practice. The condenser was designed to be placed below the cylinder; and the steam, being an expansible fluid, would, immediately on being released from the cylinder, enter also the condenser, and of course fill both, establishing a pressure of equilibrium. But, if the condenser was kept cool by being placed in a tank of cold water, steam would continue to enter until the whole was condensed. This is exactly what Watt did. In time, the condenser would become full of condensed steam, and therefore the service of an air-pump to clear the condenser was seen to be inseparably connected with it. Here, then, was that great source of loss extinguished, the steam being condensed in a separate vessel, and the heat of the working cylinder, stroke after stroke, undiminished, and its temperature maintained. Plate I. shows the latest improvement in the condenser O and air-pump P.

The exhaust-steam is supposed to be leaving the under side of the piston, Plate I., and on its way down the exhaust or eduction pipe to the condenser, where a jet of water is ready to condense it. Here is the principle by which this kind of condenser—the jet-condenser—is distinguished. The steam, coming in contact with cold water, is instantly condensed, and drops to the bottom of the condenser; when all the steam is dropped in the same manner, a vacuum is formed between the

water in the condenser and the under side of the piston, and the steam which is *above* the piston therefore has no atmospheric pressure to overcome. If there were no vacuum, there would be 15 lbs. of atmospheric pressure per square inch opposed to the descent of the piston D, by which a proportionate part of the work of the steam would be lost in keeping the atmospheric air out of the cylinder. By the ordinary method of injection, condensation is not effected instantaneously but gradually, by reason that the quantity of water necessary to condense the cylinder-ful of steam must occupy some time in passing through the injection-rose. Therefore there remains at first a counter-pressure against the piston, greatest at the commencement of the stroke, and gradually diminishing as the condensation becomes more perfect.

The term vacuum, as used by enginemen with reference to the condenser, is understood, as a comparative term, to signify the absence of pressure more or less below the atmospheric datum. We know that the atmosphere will support a column of mercury 30 inches high. Now when an engineman states that he has 20 inches of vacuum, he means that the excess of the pressure of the atmosphere above the pressure in the condenser will support a column of mercury of 20 inches vertical height; or, in other words, he tells us that the pressure of the vapour in the condenser is equal to the difference between the indications of the barometer and the vacuum gauge. If the barometer stands at 30 inches = 15 lbs., and there is 20 inches vacuum = 10 lbs., then the pressure of the vapour in the condenser is 15 lbs. less 10 lbs. = 5 lbs.

Air-pump, P.—The air-pump is fitted with valves.

There are valves at the bottom of the condenser, and there are valves above the bucket. The first are the bucket-valves, the second are the suction-valves, and the third are the delivery-valves. Formerly, these valves were single, and therefore when one failed the pump was entirely useless. When there are two or more valves, if one fails the pump can still be worked, and the condenser kept free from water. The water and air occupying the lower part of the pump below P have been drawn from the condenser through the suction-valves P during the up-stroke; descending into the water, the bucket-valves open to allow the water to pass through the bucket to the upper side; and when the bucket arrives at the foot of the stroke they are closed by the weight of the water. When the air-pump-bucket is raised for the up-stroke the water is lifted through the delivery-valve P 2 to the hot-well, and at the same time the air and water are drawn from the condenser through the suction-valve into the air-pump, in which a vacuum is formed during the up-stroke, inducing the water to leave the condenser and fill it. The packing for the air-pump bucket consists generally of tarred hemp-rope, lightly wound on and properly beaten into the recess turned in the edge of the bucket.

Cold-Water Pump, U.—This pump is fitted with a foot-valve and a head-valve. It draws water from a well or a tank, and delivers it above the head-valve into the cold-water cistern through the pipe T 2. The water flows into the pump through the foot-valve T 1 as the bucket is making the up-stroke. When it reaches the top of the stroke the bucket descends, the foot-valve is closed, and the head-valve is opened. This

pump is used to supply water for injection. The water enters the condenser, which stands in it, through the sluice o 2. Here may be found a lesson in hydrostatics. The pressure of water is upwards as well as downwards, otherwise it would not ascend the sluice-pipe.

That fluids press equally in all directions is seen in a variety of cases. If water is poured into one limb of a bent tube it will find its own level, enter the other limb, and appear at an equal height in both limbs. So that, so long as the cold-water pump supplies the cistern with water sufficiently deep to cover the condenser, the injection is in constant action and condenses the steam.

Hot-well, R.—After the water has passed from the cistern through the injection-sluice and condensed the steam, it is pumped, as already explained, into the hot-well, together with the condensed steam. The temperature of the water is generally about 100° Fahr., and is governed by the regulation of the injection water. A higher temperature would injure india-rubber valves; a lower temperature would cool down the cylinder too much, and cause a waste of fuel by re-heating it.

The water from the hot-well supplies the boilers. It is pumped by the plunger W. It is shown as being raised by the rod connecting it to the gudgeon W 2.

The delivery-valve W 4 to the boilers is closed and held down by the pressure of the steam and water at its back. As the plunger is raised water is drawn into the pump and occupies the vacant space left in the suction-pipe V 1. When the plunger is at the top of the stroke the pump and the suction-pipe are charged. In making the return-stroke, the plunger forces the water upwards through W 4, just above W 3, through which

valve it entered the pump. Let it be noticed here that the valve w 3 opens into the pump to admit water; and w 4 opens from the pump to allow water to leave it; so that, when the plunger descends, the water cannot get back into the hot-well. The least change in the direction of the stroke effects the closing of the valve; and the great pressure of the plunger downwards forces the water out of the suction-pipe, and drives it through the valve w 4 into the boiler. Therefore, if the pump is fully charged at each stroke, it is easy to conceive that the amount of water pushed into the delivery-pipe through w 4 is at each revolution of the engine represented by a volume equal to the capacity of the pump, or the product of the diameter of the plunger by the length of its stroke

CHAPTER V.

THE CORNISH PUMPING ENGINE—DESCRIPTION AND WORKING OF IT.

THE Cornish pumping engine, Fig. 4, of the present day retains many of the leading features of the original "Watt" engine; and, in fact, some of the earliest engines manufactured by the "great man" were used in Cornwall to pump water out of the mines, and to keep them free from the influx of water which constantly pours in from the "lodes," as the metal-bearing veins are called in Cornwall. Improvements were subsequently effected by local engineers—notably by Woolf, Hornblower, Trevithick, and Grose. The modern Cornish engine has been brought to such a degree of perfection that "Taylor's" engine at the United Mines, Cornwall, is stated to have lifted 107,000,000 lbs. one foot high by the consumption of 112 lbs. of coal.

The chief peculiarity of the Cornish engine consists in the facility with which the number of strokes per minute may be regulated, varying from one stroke in ten minutes, to ten or even more strokes in one minute. This was a feature to which Watt drew particular attention in the description of his engine; and it has never been lost sight of by mining engineers. The

speed cannot be so effectually controlled in any other steam-engine as in the type now under consideration.

The changes of speed are effected by means of an

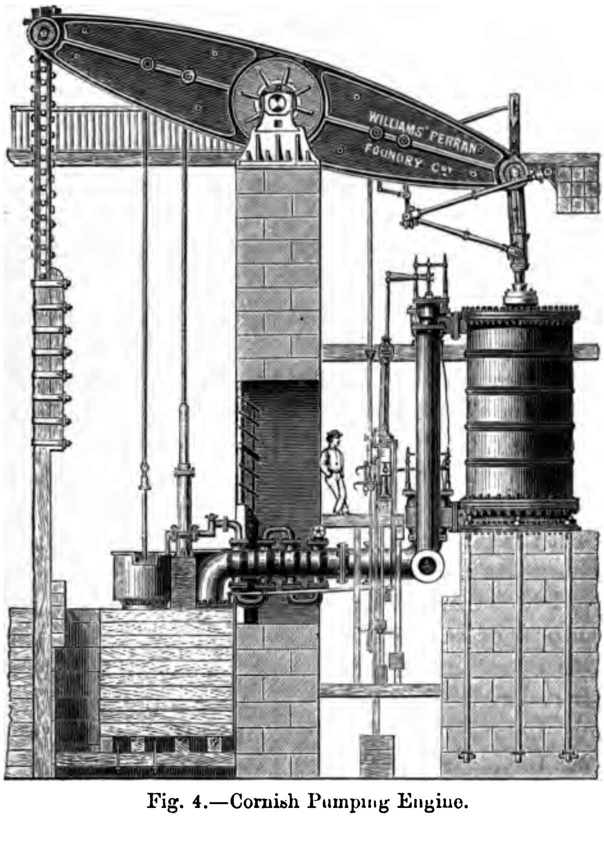


Fig. 4.—Cornish Pumping Engine.

ingenious piece of mechanism known as the "cataract," an apparatus which is fixed in the "cock-pit" or lower floor of a Cornish pumping engine. It may be either

of the "box" or the "plunger" type, the former being the cheapest in first cost, and the latter the most sensitive in working.

The plunger cataract is the type most commonly employed in modern Cornish engines. It consists of a cast-iron cistern, carrying within it a trunk-plunger and case, fitted with an inlet-valve and outlet-cock, both on the under side of the plunger.

The upper end of the trunk-rod is attached to a lever which is moved by the plug-rod of the engine, either in an upward or a downward direction, according as the steam-valve or the equilibrium-valve is worked by the cataract.

It will suffice to explain the action of the "steam" cataract which controls the opening of the exhaust and the steam valves, as the action of the equilibrium or "outdoor" cataract is precisely the same as that of the steam cataract reversed. When the piston rises from the bottom to the top of the cylinder, it lifts in the course of its ascent the lever of the cataract, and with it the plunger attached to it, causing the plunger to charge its case with water by means of the inlet-valve before mentioned; when the stroke is completed, the case is of course filled with water which can only escape by means of the cock before mentioned. The outer end of the lever of the plunger is prolonged upwards towards the gearing of the engine, so as to release the steam and the exhaust catches in its upward movement. It follows that the period of release can be regulated with exactness by the adjustment of the outlet-cock, for it is evident that the more slowly the water makes its escape, the more slowly does the releasing-gear—or cataract-loop, as it is technically

termed—rise, and *vice versâ*. The power of regulating and controlling the speed in the manner described is a point which is of the greatest importance in the case of an engine which has to drain a mine or a colliery.

Starting the Engine.—In starting a Cornish engine to work for the first time, or after a long stoppage, the greatest caution should be observed with regard to the regulation of the injection-water admitted to the condenser.

As little water as possible should be admitted at first, for otherwise the engine will probably "flood" herself, or, in other words, get the condenser and the air-pump so full of water that the pump will be unable to clear itself; or, if the water be actually cleared out, it will probably be done so suddenly that, unless the driver keeps a sharp eye on his engine, and shuts the exhaust-handle quickly, the engine will come too fast "indoor" and make havoc of his spring-beam, and possibly of his "girder." This casualty is by no means of infrequent occurrence in Cornish engines, owing to the breaking of the "main" rod which goes down the shaft or pit, and is connected to the various plungers and bucket-lifts in the mine shaft. But all evil consequences arising from this case may be averted by the use of the safety cataract, by means of which, in the event of the engine making her "indoor" stroke too rapidly, the equilibrium cataract is at once released, and the steam is admitted to the bottom of the cylinder, where it acts as a cushion to break the force of the sudden downward movement of the piston, which would otherwise arise from the release of the steam loaded piston from its load in the shaft.

Steam is usually worked in the Cornish engine with

a cut-off of about one-third ($\frac{1}{3}$), or two-fifths ($\frac{2}{5}$); although it has been worked as high as one-eleventh ($\frac{1}{11}$), when the precaution previously referred to was observed as regards a safety cataract. There is no doubt that a high pressure of steam and an early cut-off suit the Cornish engine best, as they do other engines. This was the life-long practice of Captain Samuel Grose, who did much to improve the effectiveness, economy, and general appearance of the Cornish engine; and although his type of engine is not extensively known to any but Cornish engineers and drivers, there are many specimens of his genius still at work.

Let it be remembered that the Cornish engine requires delicate handling, for this reason, that it is a non-rotative engine, and there is no crank to measure out the length of the stroke, and that, in starting the engine, on the skill and dexterity with which the engineman manages his top and bottom handles will depend the life of the engine. Above all things the engine should be handled with confidence and not with timidity.

To the engine-driver, it may be said, remember that so long as you have the handle in your hand you are the master of the engine; you can stop her, reverse her, move her one inch or ten inches as easily as the driver of a locomotive can perform the same operation with his machine; but if you lose your head, or get frightened, at the gigantic inrush of the machine you have put in motion, you had better give up the idea of working a Cornish engine. It requires a cool head, and a strong mind.

There are a few rules for working a Cornish engine that are worth remembering:—

1. Keep the cataract well supplied with water.
2. See that the exhaust and the equilibrium handles are sound forgings, free from flaws. The breaking of either of these may wreck an engine.
3. Be satisfied that cylinder and nozzle-laggings are well lined with sawdust, or other non-conducting material; and that, if the cylinder has a case, the steam-pipe to, and the drain-pipe from, it are working freely.
4. Never institute experiments with your engine for the amusement of visitors. The engine has a regular amount of work to do, and the less you interfere with or interrupt that regularity the better the result. Stop, and start, and run at all kinds of speed, and you will cause priming to an indefinite extent.
5. When stopping an engine always secure both handles with the chain or the rods provided, and shut the governor-valve.
6. Keep your engine clean, and keep everything arranged on a system. Display as much taste in the hanging up of tools as possible. Make monograms; do something besides the bare fact of what you are expected to do. Excellence in any branch of life implies voluntary exertion.

CHAPTER VI.

THE HORIZONTAL ENGINE—SEMI-PORTABLE ENGINE.

THE horizontal engine selected for detailed illustration in Plate II. and Fig. 5, is Robey's patent, one of a numerous class specially designed for stationary purposes, such as winding. It is also selected for the opportunity of referring to the system of firing in fire-boxes of the class here illustrated. A is the chimney, B smoke-box, C barrel of boiler, D fire-box shell, E safety-valve, F steam-pressure gauge, G water-gauge, H fire-hole door, K boiler tubes, L foundation-plate, M fly-wheel, N connecting-rod, O crank-shaft, P excentric-rod, Q piston-rod, R cross-head, S slide-bar, T cylinder-cover, U governor, V feed-pump, W clack-box, X stop-cock for pump, Y regulator-handle, 1 steam-chest, 2 valve-spindle, 3 valve-spindle guide, 4 holding-down bolts, 5 big end of connecting-rod, 6 main bearing of crank-shaft, 7 excentric-strap, 8 spark-arrester, 9 chimney-cap.

The boiler is of the locomotive type, containing flue-tubes and fire-box. The tubes are made of brass; the ends are expanded and made fast by a tube-expander, and ferrules are afterwards driven in at the fire-box end. The fire-box is, according to usual practice, made of copper; and is put together with iron rivets. It is

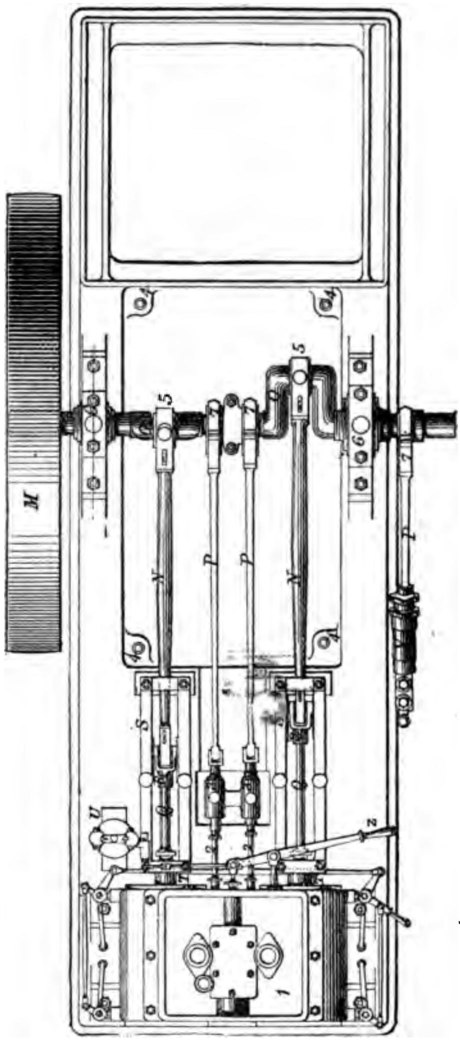


Fig. 5.—Semi-portable Engine.

fastened to the outer shell by means of a wrought-iron ring or bar, at the bottom, and another at the fire-hole.

These rings—the former of which is known as the foundation-ring, and the latter the fire-hole ring—are of the very best iron, and are carefully fitted between the fire-box and the shell, so that after these are riveted together they may be steamtight.

The sides or walls of the fire-box are further secured to the shell by copper stay-bolts. The top or crown of the box is specially strengthened, to prevent its collapsing under the pressure of the steam. The liability of the top of the box to collapse is increased by the boiler running short of water, when the copper-plate becomes much weakened.

The sides and top of the smoke-box are generally in one plate, and are secured to the boiler by means of a flanged tube-plate, which is secured to the barrel of the boiler by means of a solid angle-iron ring. The whole are of iron, and they are united with iron rivets.

The boiler-mountings include the various screw-plugs for letting out water, and for washing out; the whistle, gauge, standards, clack-boxes, valves, and safety-valves.

The cylinders are formed of cast-iron, bored out, and made perfectly cylindrical. They are bolted to the frame-plate by turned bolts passing through carefully-drilled holes, and the bolts are made to fit the holes with the utmost degree of exactness. The centre lines of the cylinders after they have been bolted together are parallel to each other. The slide-bars are parallel with the cylinders, and the crank-axle is exactly at

right angles to the line of the cylinders and valve-faces.

The crank-axle is of iron, and the throws are slotted out at right angles to each other so that when a big-end is on one dead-centre, the other is under the full pressure of steam. The shaft is fitted with four excentric-sheaves, by two of which the engine is worked in fore-gear, and by two in reversed gear. The position of these sheaves is due to the movement of the valve and piston, when one big-end is on the dead-centre, the excentric is fixed at about right-angles with it, in advance.

When the crank is placed on one of the dead-centres, a line is drawn through the centre of the web, and a circle is described on the centre of the axle equal in diameter to the travel of the slide-valve. In advance of the centre of the circle, in a direction opposed to the crank-arm, a distance is marked off equal to the sum of the lap and the lead; and a perpendicular is drawn to the centre line of the web intersecting the circle above and below the centre line. The two points of intersection show where the centre of the excentric must fall, for forward and for reversed gear. The excentric-rods are connected to the link, and the horizontal motion of the link is communicated by the joint action of the excentrics. At the centre of the link, the horizontal motion is equal to twice the linear advance of the excentrics, and it increases towards each end of the link. The movement of the link is conveyed through the block or die in the link to the slide-valve, which receives the maximum travel; when either of the excentric-rods occupies a position in a line as near as is possible with the valve-spindle, then the valve

receives the maximum throw of the excentric. The general principles of lead and lap have been described elsewhere in this book.* The action of the blast being discharged into the chimney has the effect of inducing the air to leave the smoke-box and chimney with the exhaust-steam, and thus creating a partial vacuum in the tubes from whence the air rushes to fill the smoke-box and chimney again, whilst the air in the fire-box rushes into the tubes, and the air in the ash-pit rushes into the fire. This process, if rapidly kept up, produces a constant and powerful draft of air continually passing through the fire, and the coals then receive a sufficient quantity of it in combustion to keep up the supply of steam.

Management of the Engine.—How is this engine to be managed with success? It is very natural for those who have had charge of engines to examine them when they hear something knocking, or smell something which is getting warm, or to question the state of the fire when short of steam; but, as to having any decided method of treatment, and adhering to it day after day, and year after year, because it is based upon sound rules, it is out of the question. By the non-observance of simple rules, every failure is set down to the engine.

What are those simple rules which lead up to and command success at engine-driving?

1st. From the hour an engine and boiler are set to work they are acted upon by destroying forces, and, therefore, there should be on the part of the attendant an undeviating conviction that these must be habitually followed up, detected, attacked, and effectually pre-

* See page 58.

vented from rapidly, gradually, or uniformly disabling the machine in his charge.

These destroying forces present themselves in different forms, each having a character of its own, and the only way to overrule them is to know them. One is wear, and the other is tear. The simplest, and at the same time the most efficient method of detecting wear, is to examine the engine twice a day, systematically. Not looking askance at the machinery, roughly to detect tear and his brass filing; or into the fire-box to see if he has brought the crown nearer to the bars; but to detect the progress of ordinary wear in its simplest character and effects. The presence of this, as well as the greater evil, tear, is generally not difficult to detect.

Before the engine is allowed to make a single stroke it should be examined all round, commencing at the crank-shaft bearing. Brasses do best, wear longest, and knock least, when tightened up a little at a time, and before they attract attention by knocking. Trimmings do best when they are kept dry or free from wet, when not choked with tallow, and when free from the presence of glutinous matter; and, further, tail-trimmings should be taken out of the syphon-pipes, when the fire is withdrawn; and, before they are replaced, it is advisable to pour a little oil down the pipe so as to allow time for the trimming to commence working. This precaution will, in many instances, prevent a journal or a slide-bar from cutting. The oil-box should, now and then, be carefully cleaned, because very few boxes are so made as to exclude every particle of dust and dirt, and besides many oils contain india-rubber and resin in solution.

The big-ends require plug-trimmings, made of copper-wire and worsted. The wire is first doubled and then plaited in the middle several times; the bow at one end requires to be cut and the ends opened out. The worsted is then wound over and over until the plug can fit the syphon-pipe easily, not too tightly nor too slack. One end of the wire is then turned over to embrace the worsted, and the other outwards so as to fall over the top of the syphon-pipe, and to suspend the plug in it, which should not touch the journal; and at the top it should form a small reservoir for oil in the pipe by being adjusted down the pipe about three-eighths or half-inch. Such trimmings can be placed in all swinging motions.

The excentrics should be always kept in good order so as to prevent the lead of the valve from being altered. It is a good plan for a young engineman to notice their position in relation to the cranks, so that if one happened to shift by the slackening of a set-pin or a key, he could set it back into its right position.

When the engine is put into middle gear, the links can be thoroughly inspected, and great care is required to see that the split-pins in the fork-ends of the excentric-rods connecting them to the link are all well bedded.

The glands require special supervision to keep them fair with the rods, and to keep them from "blowing" steam, by packing them in time. Nothing looks so slovenly about an engine-house as leaking glands, moist steam blowing over the little-end and destroying the trimming by making it wet. When one side of the engine is done, the other should receive the same attention, and even more, for some people are apt to

conclude that because one side is right the other is so also.

The smoke-box and the ash-pan require to be cleaned out thoroughly every day.

Should the engineman require to test the valves and pistons, both little-ends must stand opposite each other and as near the front end of the slide bars as possible, when one crank will be above the shaft and one below it. If steam is put on slightly, that will test the left-hand piston; and if the engine is reversed, that will test the right-hand piston. If the engine is put in mid-gear, that will test the valves.

Further information on testing and setting valves is given in "Locomotive Engine-driving."* Now it is a good thing to have made an efficient examination, and to have ascertained that the engine is in thorough working order. But this is only a portion of what is required to insure success. There must be—

Secondly. A thorough knowledge how to burn coals with the least quantity of smoke, and to obtain the largest quantity of heat from them. Without this knowledge, no man can become a first-rate engineman. A skilful man seldom fails to seize this important element of good management. Now, it is a fact that hundreds of boilers having square fire-boxes, such as are found in ordinary portable thrashing-engines, are fired without the skill which is necessary to insure economy, and to maintain the steam regularly. When coke was used, the enginemen were in the habit of shovelling it into the fire-box without any regard or doubt as to whether there was a right or a wrong way to make a fire. The

* "Locomotive Engine Driving." Fourth edition. 1880. Crosby Lockwood & Co.

same indifference prevailed when coal was used. With regard to the form of a fire, what alterations were made were confined to the shape of the fire-box, and not so much to the shape of the fire. But coal-burning fire-boxes at last returned nearly to the shape of the coke-burning boxes, and attention was given to the shape of the fire; the fire was made sloping, for in the sloping boxes most of the fires were level, and the boilers would not supply sufficient steam, for the simple reason, that coal can only be burned economically when a current of air is constantly rushing through it. To effect that object, we must have regard to two things, namely, the shape of the fire, and the depth of the fire.

When the fire is hay-cock shape—highest in the centre—which may be found in thousands of instances, the necessary amount of air to carry on the process of combustion is obtained up the sides of the fire-box, and the gases there seize their portion of oxygen, and the body of the fuel is starved. The result is that when the fuel about the sides is consumed, a passage for air is made for it to enter the box and tubes without giving up sufficient oxygen to maintain steam. The fire-irons are then set to work to stop the leakage of air, and waste the fuel. There is another evil; when the fire-box draws air up the sides, the cold air comes in direct contact with the walls of the box, causing intermittent expansion and contraction, both in the box and in the tubes. The fire should be made shallow at the middle, and built up all round close against the plates. This fire will make steam when others will not; and in thousands of instances it has been found to make steam better than any other. It consumes its own smoke,

and it is the only way to obtain all the goodness out of the coal; and, further, what is of equal importance, it keeps the fire-box cold-air tight. It is well known in the locomotive service that the fire in question is one that consumes the least fuel and gives the least trouble; and what is best on a railway engine is equally valuable in the boilers of the same class employed in stationary service.

The fire should be renewed as soon as the gases come to receive their equivalent quantities of air, and this is known when perfect combustion is taking place, when no smoke is visible, and when the steam begins to leave the valves. By opening the fire-door, the steam is slightly checked, and is prevented from blowing off.

The depth of the fire should be regulated by the work upon the piston, or, in other terms, the fire should be no deeper than what admits of the air being drawn through by the blast or exhaust steam. Much of the economy in fuel depends upon the amount of air a driver can get through the fire. If the fire is too deep for the blast, the slag and refuse in the coal will settle on the fire-bars; but, provided the fire is of the proper depth, and a strong current of air is kept constantly going through it, the oxygen, by coming in contact with the refuse, will split it up into atoms, and carry it into the tubes and smoke-box. By firing a little and often, this may be done all the day through, and at the close, the fire-bars will be found quite free from caked clinker. The fact of firing round the box will necessarily deposit the dirt, &c., in the coal around the outside, which will assist in compelling the air to come through the centre. By doing so, it is instantly rarefied and spreads around, as water does from a rose on

a water-can, and enters the tubes at a very high temperature, assisting them to maintain an even pressure in the boiler.

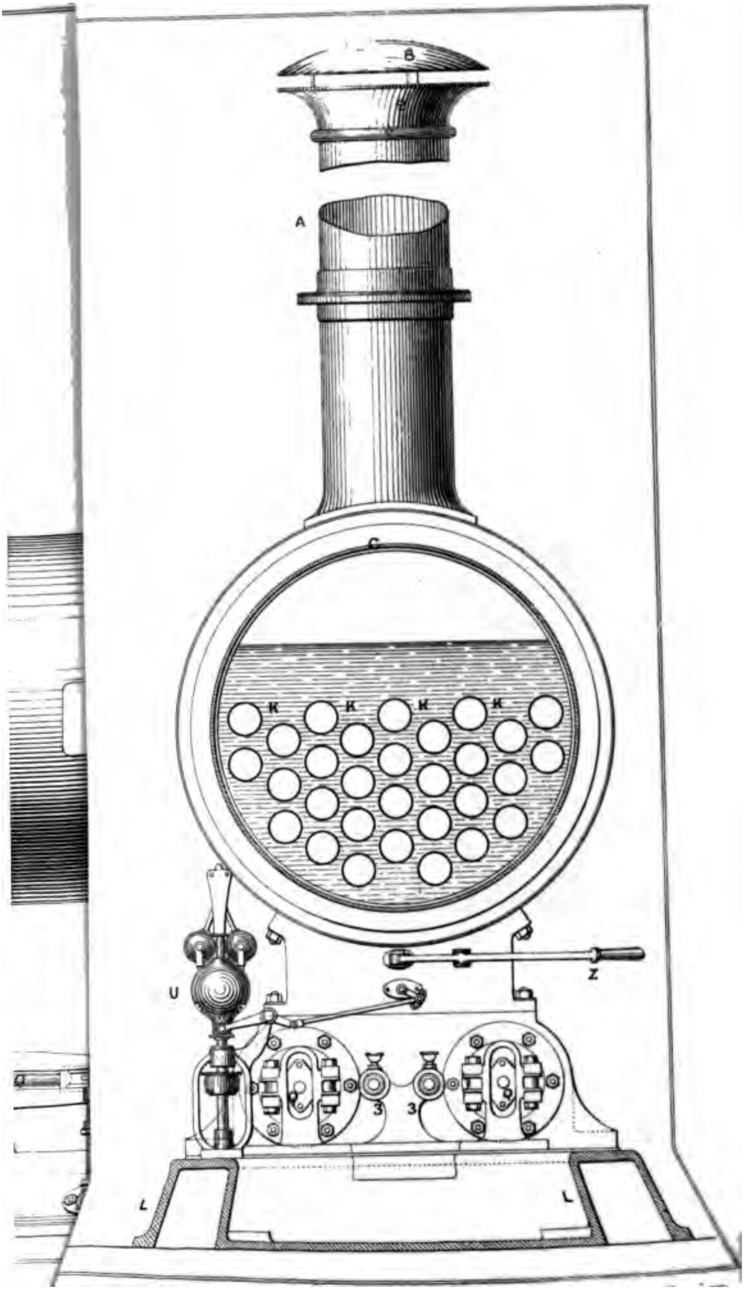
When a large quantity of green coal is charged into a fire-box, it gives off vapours and tarry matters which adhere to the tubes, and then they become coated with what is commonly called soot, which is unconsumed coal deposited there in minute particles. A round of six small shovelfuls of coal, one in each corner, commencing at the left front corner, with one at the middle of the tube-plate, and one under the door, should be quite sufficient in all cases. The best of the coals will fall to the centre, and a cone-like column of fire will rise from there and strike the crown of the box, giving up much of its heat to the water before entering the tubes; and this is how it should be.

Much wasteful and unscientific firing is caused by a wrongly shaped fire, by having a fire too deep, and by heavy firing. By adopting the plan herein advocated, there will be less coal used, less smoke, regular supply of steam, less tube cleaning, less ashes, and a clean hearth.

Lastly. An engineman may follow out to the letter all that is here recommended; but there is one more point of importance, which should be mentioned here; and that is, the supply of water to the boiler must be regular.

It should be kept at one level in the glass, never allowed to enter the cylinders, but used freely as often as possible to make the boiler clean, and yield pure steam.

Plate 11.



CHAPTER VII.

COMPOUND ENGINES.

GREAT as was the degree to which the steam-engine had been brought by the fertile brain of James Watt, there was left ample scope for the exercise of talent, perseverance, and invention; there was still a wide field and abundant material for the exercise of ingenuity. One of the first geniuses in Watt's time, who endeavoured to reach a stage in advance of all others, was Jonathan Hornblower, a Cornish engineer of no mean repute, and a contemporary of Trevithick, Murdoch, and Woolf.

Without doubt Elihu Burritt was right when he wrote, "In human communities the collision of mind with mind contributes fortuitous scintillations of intelligence to their general enlightenment." The introduction of Watt's engines into Cornwall, together with the presence of his able assistants amongst Cornish thinking men, gave origin to scintillations of brilliant ideas. The idea which emanated from Hornblower's brain was the compound engine, in which he employed the steam, after it had done its duty in one cylinder, to work the piston in another cylinder. "I use two steam vessels," said Hornblower, "in which steam is to act, and which in other steam-engines are called

cylinders. I employ the steam, after it has acted in the first vessel, to operate a second time in the other vessel, by permitting it to expand itself, which I do by connecting the vessels together and forming proper channels and apertures whereby the steam shall occasionally go in and out of the said vessels."

Many were the hopes of the inventor regarding this engine and its superiority in economy of fuel over all its predecessors, but he said too much in his specification. After he had given an explanation why he intended using two cylinders, he went on to describe his condenser, beam, and other connections, the resemblance of which to Watt's arrangements led to a searching inquiry into the real merits of the engine. Unfortunately for Hornblower, it was decided that he had trespassed upon Watt's patents, and that the same effect was produced by Watt in one cylinder as Hornblower professed to do with two. This decision had the effect of directing the public attention in another direction. The engine proved to be all Watt's excepting a little bit.

The invention of using two cylinders, however, was never actually abandoned. Its details have been worked out to such an advantage that compound engines have much to recommend them, and therefore it is necessary that the principle should be understood by enginemen.

There were at first many objections to compound engines, arising from the complication of their construction with numerous joints. Such plans have been abandoned for simpler arrangements.

The fact of low-pressure steam being in fashion in Hornblower's time considerably annulled the advan

tages which were sought for; modern practice has secured for the compound engine considerable advantage over that of the past by the employment of a higher pressure of steam. Many varieties of design exist, but the mechanical action of the steam is the same in all. It is begun in one cylinder and ended in the other.

The steam at a high pressure (from 60 to 80 lbs.), first enters the smaller cylinder, and follows the piston until it has moved through a certain portion of the stroke, when the valve cuts the steam off. The remainder of the stroke is performed by the expansion of the steam shut up in the cylinder, as in an ordinary single-cylinder engine. When the steam has done its work, that is to say, when it has pushed the piston to nearly the end of the cylinder, instead of being released into the air or the condenser, it is released into the second cylinder, where it acts upon the piston just as it did on the piston in the other cylinder, but at a lower pressure. Having done an equal or proportionate amount of work in the second and larger cylinder, it is thence exhausted into the condenser. Sometimes the cylinders are placed by the side of each other, and sometimes one above the other, the smaller on the top of the larger, having only one piston-rod continued through both cylinders and pistons, one connecting-rod and one crank.

Why do we use cylinders of different dimensions? If the cylinders were both of the same diameter and stroke there would be no useful result. How is that? If they were of the same capacity when the steam was released, it would act by back pressure on one piston as much as by positive pressure on the other piston

and the process would be simply a transference of steam from one cylinder to the other. Suppose that steam of 50 lbs. pressure is ready to be released from a 24-inch cylinder, and that it is allowed to enter another cylinder 24 inches diameter. The area of each of the pistons is 452·4, and 452·4 multiplied by 50 = 22,620 pounds total pressure, and the steam would oppose just as much as it would force. Now, if the same steam be released into a second cylinder having a piston area of 904·8 inches, which is twice the area of the smaller cylinder, it will exert an amount of pressure double what it does on the smaller piston. As a rule, the proportion between the areas of the two pistons is not double, but in the proportion of 1 to 4; and it is in virtue of this difference of areas that the useful work done by expanding steam in a compound engine is produced. Strictly speaking, the ratio of the areas of the two cylinders is not definitely fixed, nor is the steam in all cases exhausted direct from the smaller cylinder into the larger one, nor is the gain of work by expansion the sole consideration in using a compound engine. There is another object—to secure steady motion, and at the same time to carry out the principle of expansion with the least possible amount of injurious effect upon the machinery, by reducing the extremes of pressure in the cylinders. In expanding steam to an extreme degree in one large cylinder, a variety of evils are produced, which are obviated by the employment of two cylinders, in which the steam is expanded in succession, whilst the steam would in the single cylinder exert at the commencement of the stroke a pressure probably sufficient to do twice the work required of it, and at the end of the stroke a pressure probably only

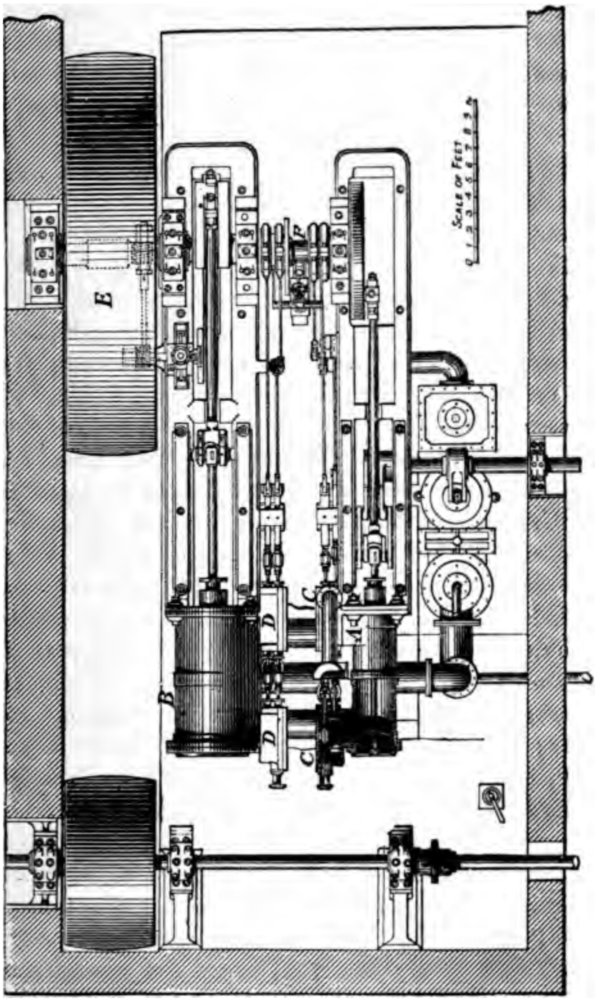


Fig. 6.—Compound Hoiizontal Engine.

half. Such irregular motion may be produced as might not only overstrain the engine, but the variation of the temperature of the steam in the cylinder would take place also in the temperature of the metal of the cylinder, and would react with an injurious effect sufficiently to make expansive working an expensive working. It may be added that the larger cylinder of a compound engine exhausts into the condenser.

The horizontal compound engine illustrated by Fig. 6, represents a kind of engine now extensively employed in mills for textile manufacture. Both the high-pressure cylinder A, and the low-pressure cylinder B, are fitted with double-slide chests, C, C, D, D, the object of which is chiefly to secure shortness of steam passages, readiness of access to the valves, and space between the two chests of each cylinder for adjustment of the valve-rods. The slide-valves are of the Meyer type, and are adjustable by means of right-hand and left-hand screws. The high-pressure cylinder is controlled by Allen's expansion-gear; the low-pressure cylinder is fitted with adjustable expansion gear. The exhaust from the high-pressure cylinder to the low-pressure cylinder takes place through two separate pipes; and the cranks being separated by an angle of 140°, and the low-pressure cylinder being ready to receive steam at the instant of its relief from the high-pressure cylinder, there is no necessity for a special intermediate receiver. A large drum, E, is fixed on the crank-shaft, F, from which the power is taken off by a leather belt. The cylinders are respectively 21 inches and 40 inches in diameter, and the stroke is 5 feet, making sixty revolutions per minute.

CHAPTER VIII.

CORNISH AND LANCASHIRE BOILERS.

THE system of employing steam became more generally recognised as the practical difficulties of obtaining a sufficient supply were gradually removed. There was no doubt about the economy resulting from the employment of steam, and no attempt was made to replace steam as a prime mover. The difficulties lay with the boiler. The cry was for more steam! New and larger cylinders were employed, and the demand for steam was consequently on the increase. The materials of which the earlier boilers were made exhibited unmistakable signs of weakness, and therefore cast-iron was replaced by wrought-iron for the construction of boilers. Still the mining engineers were daily making out plans for larger pumps and larger buckets with which the manufacturer of engines could not interfere; he had to find the power to work them.

There was a distinct relation between the engineer of a mining-field and the maker of steam-engines, and to this may be traced much of the improvements which attended the use of steam in its infancy. The mining engineer had no connection at all with the engine factory, and the engine-maker on no account undertook to make a drawing of pumps, lifts, &c., to drain mines.

All he engaged to do was to supply steam and machinery to help to clear a drowned-out pit.

The mining engineer was unharassed by the cares of the factory, so he could devote the whole of his energies to designing pumps. The engine-maker was unharassed by the mines, so he could give the whole of his attention to the workshop and the improvement of the steam-engine. This was imperatively necessary on account of improved mining constructions. The harmony and the distinction of interests led to a better boiler from the hands of the maker, who might just as well have shut up his shop as have closed his eyes to the fact that engineering skill was required to satisfy the call for more power. Every day's experience taught this, and many means were used to gain the desired end; but how to commence the matter was a riddle to many. A fear to deviate from a beaten track, a bigoted attachment to some favourite principle, and the want of means to conduct experiments free from theoretical reasoning, tended to keep from view the great desideratum, which was a superior boiler. But, for a long period, men looked in another direction: master minds—Watt to wit. The great mind of Watt was devoted to improving the engine and economising the steam; at the same time he was bent on keeping the pressure down. Hornblower went at the same kind of thing; but Watt, finding the world was going faster than he or others could keep pace with, looked straight into the matter, and after doing all he could to save steam by improving the engine, in advance of all his contemporaries, he invented the mill-waggon boiler, which then for a time took precedence of all others and drove many of them into oblivion. He,

however, had a deal of trouble with it, owing to the pressure of steam being equal in all directions; and *he* must have known that the form of his invention was not the best to withstand centrifugal pressure; still he held to it and passed it through various modifications of form in order to strengthen it and make it a safe and rapid generator of steam. For a time, it was as illustrious as its inventor. All this time the mining engineers were passing through a labyrinth of complexities, and Cornwall was their locality.

The Cornish engineers turned their attention to the use of high-pressure steam *versus* low-pressure steam, with the view of obtaining plenty of steam more cheaply than the "waggon" boiler could supply them. So they had to scheme an entirely different boiler, and a better one than Watt's, which, by the way, had been so far improved as to contain a longitudinal flue in the middle. Richard Trevithick, an eminent Cornish engineer, invented the boiler illustrated by Figs. 7, 8, 9, and although at the time of its introduction it was known as the "Trevithick" boiler, it is better known now, in 1880, as the Cornish boiler. It should be mentioned that, at the time this boiler was invented, there were others in use, such as the horizontal externally fired boiler, known as the egg-end boiler. But Trevithick's boiler eclipsed all others by having the grate placed within the tube, through which the hot gases passed, and then down underneath to the front where they were divided, and along the sides to the chimney. The boiler takes its name from being first employed in the service of the pumping engines in Cornwall. The furnace was thus brought for the first time into the central flue and within the boiler itself,

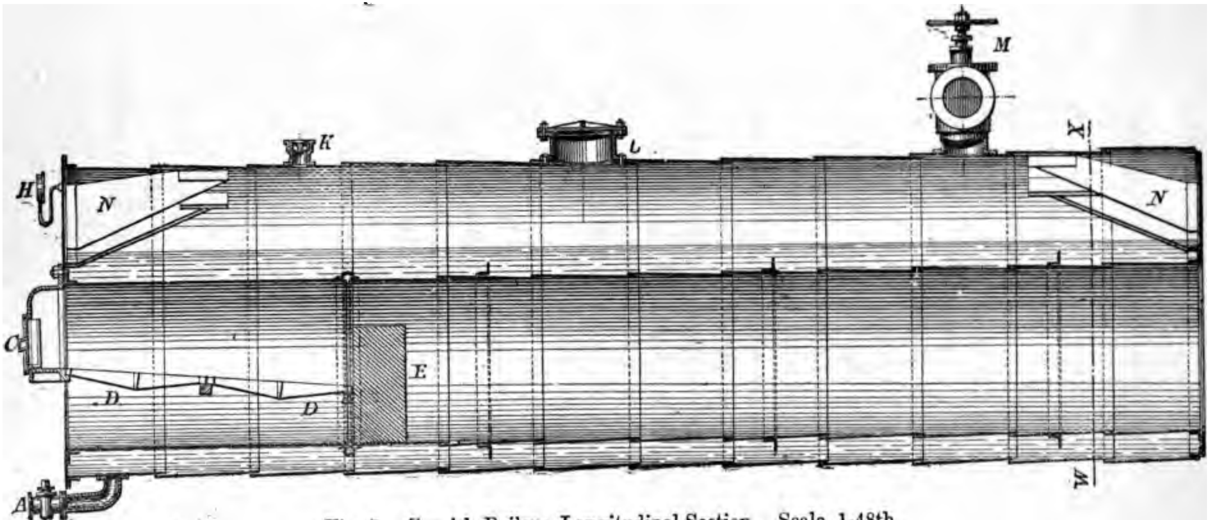


Fig. 7.—Cornish Boiler: Longitudinal Section. Scale, 1-48th.

instead of being external and underneath like all its

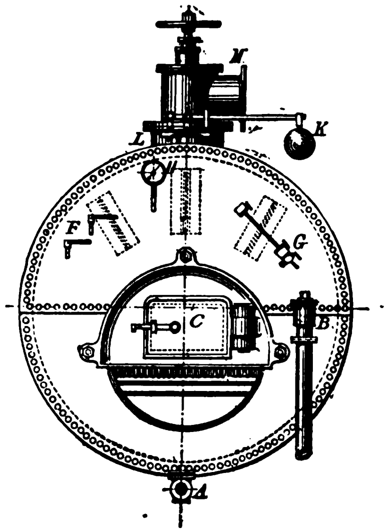


Fig. 8.—Cornish Boiler. Front View. Scale, 1-48th.

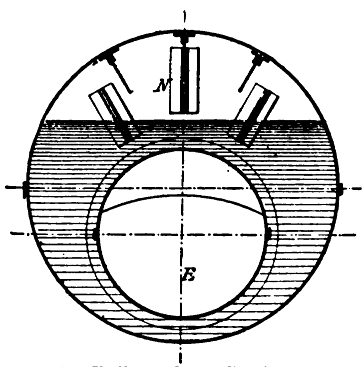


Fig. 9.—Cornish Boiler: Cross Section. Scale, 1-48th.

predecessors. How would it act?—that was the ques-

tion; and would the heat so damage the tube as to endanger the boiler? Experienced men were quick to question how it would stand the test of working. They were not surprised to find a more perfect combustion of fuel, and the heat more effectually applied. This result was found by observing the temperature of the gases after they had traversed the tubes and were about entering the chimney. In previous boilers the furnace was surrounded with brick-work which took up the *first* heat, and this penetrating into the mass of the outer walls, radiated away into the engine-house.

In the Cornish boiler, the best of the heat is usefully applied on the heating surface, and the remainder only is extracted by the masonry, so that the process of absorption was reversed. The results were highly favourable to economical working, and it very soon became popular. Many contended that, to obtain the greatest effect, the heat should be applied to the bottom of the boiler; others contended that a convex heating surface was superior to a concave one. But experience proved, when the heating medium was inside a boiler, and applied to a concave crown, it was a far superior steam generator to any that had gone before it. A concave heating surface is superior to either a flat or a convex one.

Bury's round locomotive fire-boxes would make any amount of steam, and herein their strength lay. The fire-boxes of the present day, with vertical sides and concave tops, make steam better than the square boxes.

The Cornish boiler was not only a new form of boiler, but it was made to withstand high-pressures

which frightened most people; but Trevithick intended it for high-pressure, and he was the man who introduced it for the purpose of affording scope for the carrying out of the principle of expansion by cutting off the steam earlier than others did, and, by doing so, economising fuel. When high-pressure steam is cut off very early, the inequality of the steam's action on the piston requires to be practically neutralised. This is done by the fly-wheel.

The Lancashire boiler, Figs. 10, 11, 12, is a native of Lancashire, and was the outcome of a desire to insure safety. The internal flue of large Cornish boilers occasionally exhibited signs of weakness. It was subjected to an enormous degree of expansion which bulged the ends out, and when it was stiffened and stayed, so that it would not yield, the internal tube became hog-backed within the boiler; then, by sudden contraction, when the door was opened for firing, it was straightened. Consequently the boiler became unsafe. To maintain the size of boiler necessary for the supply of steam, and to retain the principle of an internal grate, the boiler was converted in Lancashire into a double Cornish. There are reasons for inducing us to admire this boiler, from the point of view of the stoke-hole. When the furnace is six feet or more in length, it requires more than ordinary human muscular action to send the coals to the extreme end of the grate; and where there is not the strength to do so, the bars soon become bare; then, to keep the steam up, the rake is put into the fire to knock it about, and to blaze the coals away. Besides, in a big boiler with a big grate, one will generally find by the side of it, to *keep it warm*, a *big* draft. In

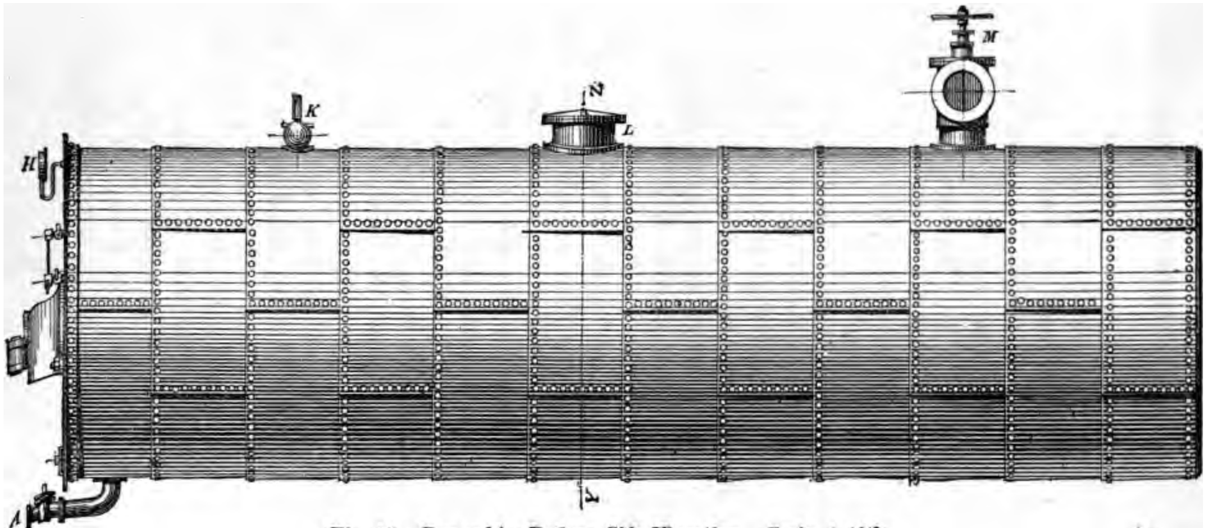


Fig. 10.—Lancashire Boiler: Side Elevation. Scale, 1-48th.

some instances, the boiler is overpowered, but as a

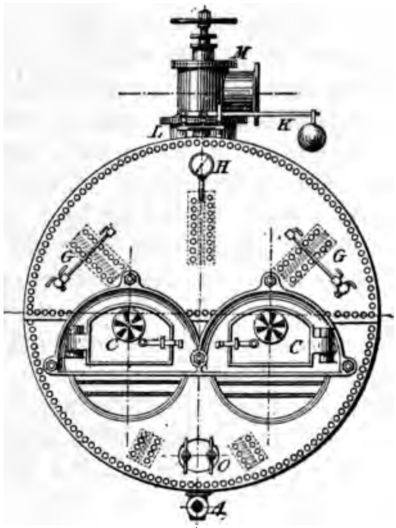


Fig. 11.—Lancashire Boiler: Front Elevation. Scale, 1-48th.

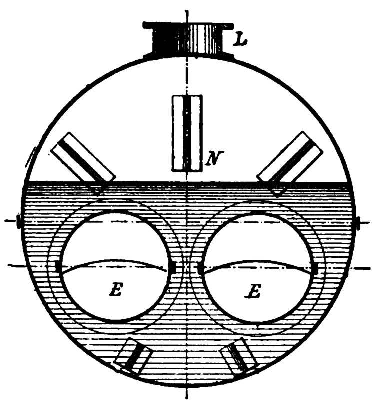
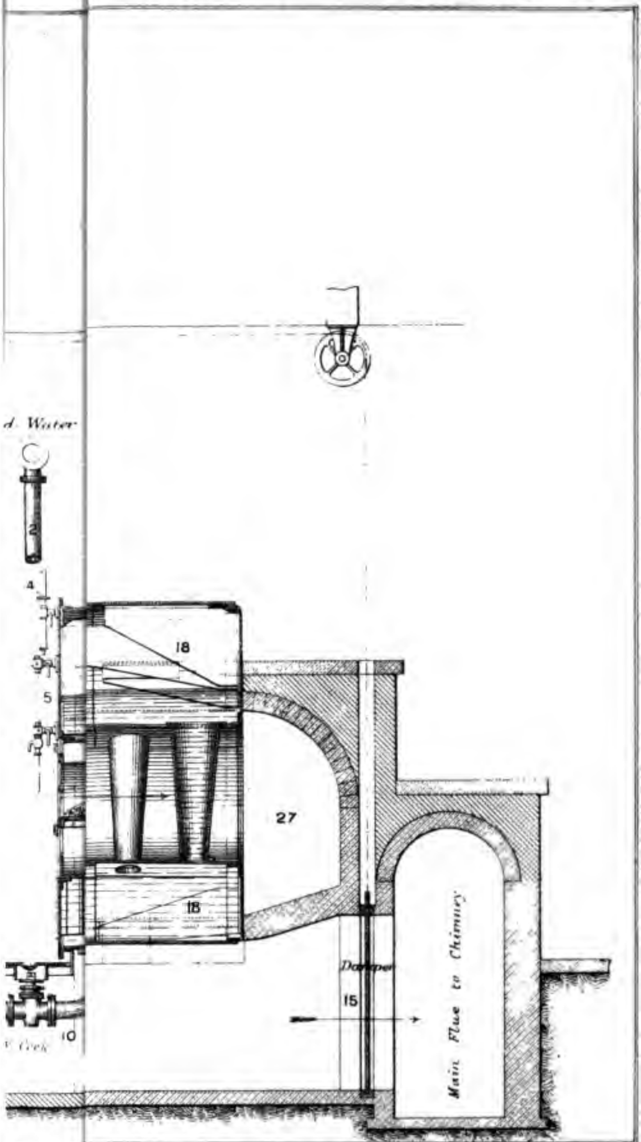


Fig. 12.—Lancashire Boiler: Cross Section. Scale, 1-48th.

rule it is done because the thing looks in keep
Now with a large grate of 6 feet long by 3 feet 4 inc
wide, the fire is too low below the furnace top for
hot gases to come in contact with the plate, and
soon as the attendant closes the fire-door, the str
draught pulls the gases out of the furnace without th
being properly ignited, or being by a slower d
allowed to touch the plate above. If, instead of
grate, we had two grates 4 feet long by 2 feet 7 inc
wide, the attendant would with certainty cover
whole grate by means of the shovel, which would ke
out the rake and save coals. Besides the fuel wou
be nearer to the crown of the furnace, and the wat
and the draft would be split.

The illustrations show the difference in the tw
constructions, and they will enable enginemen
learn the reason of one being called a Cornish, ar
the other a Lancashire boiler. As there are scarcel
two boiler-makers who put their boilers together alik
it is unnecessary, while noticing the boilers, to advoca
any particular design or class, for the simple object
this work is to explain such things as are useful, ar
are calculated to raise the mind of those in charge
engines and boilers, and to induce them to study th
questions hinted at here, in the works of others.

Plate III



Thos Kell & Son. Lith 40 King St Covent Garden.

CHAPTER IX.

THE GALLOWAY BOILER.

THE general arrangement and construction of the latest improved "Galloway" boiler is illustrated by—

Longitudinal section	Plate III.
Plan	,, IV.
Front view (Section on line A B) . . .	,, V.
,, ,, (,, ,, C D) . . .	,, V.

In many respects and in general appearance, the boiler is of the Lancashire type, which as hgiven such excellent results in England.

1. Main steam-pipe.
2. Feed-water-pipe.
3. Safety-valve.
4. Steam-gauge.
5. Water-gauge.
6. Fusible-plug.
7. Furnace.
8. Mud-hole.
9. Ash-pit plates.
10. Blow-off-cock.
11. Flue-door.
12. Steam junction-valve.
13. Man-hole.
14. Feed-water-valve.
15. Damper.
16. Damper-weight.
17. "Galloway" patent conical tubes.
18. Gusset-stays.
19. Pockets.
20. Side flue.
21. End of flue.
22. Bottom flue.
23. Fire-lumps to support boiler.
24. Water.
25. Steam or steam-space.

The Galloway boiler has now been in operation over twenty-five years, and is used in all parts of the United Kingdom, supplying steam to some of the most powerful engines, and giving great satisfaction. At the Philadelphia Exhibition of 1876, thirteen descriptions of boilers were tested, including the Galloway boiler,

with the view of ascertaining their respective merits as economical and satisfactory steam generators. Each boiler was tested separately for eight hours, observations being taken every twenty minutes, under ordinary working conditions, and a pressure of 70 lbs. to the square inch was regularly maintained throughout each trial. The test was conducted as follows:—Steam having been raised to 70 lbs., the height of water in the boiler was noted, and the fires were drawn. The fires were then relighted with fuel, which was weighed and charged against the boiler; all the additional coal supplied for the trial was also weighed as it was served out to the fireman, and allowance was made for the coal which remained unconsumed in the furnaces at the termination of the trial. Observations were made to test the state of dryness of the steam by condensing a certain weight of steam in a given quantity of water. The dampness of the steam or the moisture it contained was calculated from the increase of weight of the water and the rise of its temperature.

The feed-water supplied to the boiler was measured and also weighed, the force-pump for supplying it being fed by steam from the boiler on trial. The results arrived at are embodied in the table below, from which it will be seen that Galloway's boiler (Patent 1875) attained the most economical result, evaporating 11·72 lbs. of water at 212° Fahrenheit per pound of combustible. In addition to achieving the most efficient evaporation, the boiler yielded the driest steam. Anthracite coal was the fuel consumed in testing all the boilers, excepting the Galloway boiler, which, being more suitable for bituminous coal, was tested with that description of fuel:—

Description of Boiler.	Heating Surface in Square Feet.	Horse-power at 1 Cub. Ft. Water evaporated per Hour.	Lbs. of Water evaporated.			Percentage of Water in Steam.	Lbs. Coal burnt.		Temperature of Gases leaving Boiler.	Cub. Ft. of Water Space per Horse-power.	Cub. Ft. of Steam Space per Horse-power.
			Total.	Per Hour.	At 212° per lb. combustible.		Per Hour.	Per Sq. Foot of Grate per Hour.			
Galloway . .	973	41·64	20,824	2,603	11·72	·57	283	7·269	324	14·10	4·04
Root . . .	1,590	54·29	27,146	3,393	11·565	not taken	381	9·09	393	2·29	·89
Firmenich .	1,078	26·46	13,233	1,654	11·53	not taken	185	11·79	415	4·08	2·63
Lowe . . .	774	21·45	10,729	1,341	11·489	not taken	153	6·805	332	9·02	2·63
Babcock . .	1,680	62·70	31,358	3,919	11·489	3·24	444	9·77	295	3·74	2·20
Andrews . .	540	18·94	9,469	1,183	10·513	not taken	148	not taken	419	4·14	1·29
Wiegand . .	1,355	68·08	34,042	4,255	10·461	not taken	517	12·32	523	2·66	·64
Anderson . .	1,135	44·44	22,230	2,778	10·255	not taken	350	9·747	417	1·43	1·28
Kelly . . .	662	37·41	18,710	2,338	10·099	5·97	291	10·82	not taken	1·91	·68
Harrison . .	900	36·57	18,285	2,285	10·022	1·11	284	12·36	517	1·93	·80
Pierce . . .	200	23·74	11,876	1,485	9·818	5·53	199	7·99	573	·65	1·64
Exeter . . .	1,525	32·65	16,334	2,041	9·765	4·63	280	9·35	429	2·66	1·43
Rogers and Black	399	21·13	10,564	1,320	9·31	2·68	181	8·05	571	1·71	1·17

Description of the "Galloway" Boiler.—The shell is made of nine rings of plates, about three feet in width; each ring being made up by three plates in the circumference. The transverse riveting of the circular seams is single—that is to say, there is one row of rivets. The longitudinal riveting, for the longitudinal seams, is double riveting.

It has been found by a series of carefully conducted experiments that the double-riveted straight seam is considerably stronger than the zigzag plan.

The plating of the shell is what is termed parallel—that is, the plates are bent truly cylindrical, so that the successive rings of plates are alternately lapped inside and outside. Thus—

Fig. 13.—Plating of Boilers.

This system is an improvement on the old style of conical plating, where each ring is lapped outside at one edge and inside at the other edge. On this system all the plates are required to be cut tapering; on the other system the plates are rectangular.

The front end-plate is securely attached to the shell by an angle-iron, and is turned on its outer edge. The holes in the furnace-plates are carefully bored out in the lathe. The back end-plate is connected to the shell by flanging, so as to allow sufficient play for the expansion and contraction of the flue. At the back end the flue is connected to the shell by means of an angle-iron ring.

The furnaces are each in three rings, welded longi-

tudinally and flanged transversely with a strengthening ring between the flanges; thus all riveting is kept clear of the fire, and there is ample strength for resisting the pressure of the steam. The tubes are connected to the front end-plate by angle-iron rings. Beyond the bridge they are connected to the flue containing the pockets and patent cone tubes. This flue is concave at the bottom instead of being convex, as previously formed. By this improvement much more room is provided underneath for the passage of a man to inspect, clean, or repair the boiler. The tubes in the flue converge towards one centre, from which the curves of the top and bottom of the flue are struck. They are all alike, and are interchangeable; and as the tubes are flanged square to their centre lines, less strain is put upon them in their manufacture than when obliquely formed, as before. The tubes for these boilers are made by machinery, by which greater accuracy is secured than when they were made by hand. These tubes are $5\frac{1}{2}$ inches in diameter at the smaller end, and $10\frac{1}{2}$ inches in diameter at the larger end, so that the smaller end of the tube can be drawn through the hole cut in the flue to receive the larger end of the flue if at any time it should be required to remove a tube. Practically, it is not necessary to remove or renew a tube, as the tubes last as long as the other parts of the boiler.

The taper form of the tube allows the globules of steam to rise as they are formed, into the water, clear of the surface of the plate. This is advantageous, for if the water is kept off the plate by the steam that is generated there, the tube is liable to be overheated and burned out.

Pockets are placed in the flue, which deflect the flame amongst the tubes when it would otherwise seek a direct passage.

At the back end the flue is reduced, where it is connected to the shell, by contracting pockets, in order to allow of the necessary expansion and contraction which the flue of the boiler undergoes when at work.

The ends of the boiler are stayed to the shell by a number of gusset-plates, several of which are extended to the second plate of the shell, in order to give additional holding strength. They are attached by double angle-irons, and they are not brought nearer than eight inches to the crown of the furnace or of the flue. By such a provision scope is allowed for the expansion and contraction. If the connection were too near and too rigid the end-plate would be overstrained, and grooving would be the result.

The boiler is fitted with a pair of doors having a brass grid, by which the admission of air is regulated according to the state of the fire. Inside the furnace, at the entrance, there is a dead-plate, next to which are the fire-bars of cast-iron, in three lengths, resting upon cast-iron bearers. The fire-bars extend to the bridge, which is made of fire-bricks of a height sufficient to deflect the flame towards the crown of the flue, without checking the draught. On the front of the boiler there are two water-gauge glasses, having a pointer showing the best level at which the water should be maintained, leaving ample steam-room in the boiler. The gauge-glasses are connected at the bottom by a drip-pipe, which carries the waste water to the drain—not into the ash-pit. A steam-gauge is fixed

on the front-plate, as near to the top of the boiler as possible, in order to keep it cool and in good order. The safety-valve is placed on the first shell-plate of the boiler: consisting of a mitre-valve with a lever and a weight, which can be adjusted to any pressure. The function of the safety-valve is to give notice when the pressure of the steam rises too high, and to relieve the boiler of surplus steam. A man-hole is provided at the top of the boiler, about seventeen inches in diameter—sufficiently large to allow a man to get inside the boiler.

There is a mud-hole B at the front. Underneath the boiler, near the front, there is a blow-off-cock, 10, which is connected by a curved pipe to a stand-pipe riveted on the boiler. This cock is opened at intervals during the day to let off the mud which collects at the bottom of the boiler. It is also opened when the boiler is required to be blown-off altogether.

A steam-nozzle or stop-valve, 12, is also provided. It is a valve which is set down or closed by means of a hand-wheel and screw. Underneath the nozzle, inside the boiler, there is an anti-priming pipe, which is formed with a number of perforations, through which all the steam passes from the boiler for the supply of the engine. The water is separated in the passage, and is sent back into the boiler; thus a supply of dry steam is reserved.

The main feed-water-pipe is connected to a feed-valve by a curved pipe, as shown. This valve acts also as a back-pressure valve; that is to say, although it allows water to pass into the boiler, it does not allow the water to return.

Inside the boiler there is a long perforated pipe, by

which the water is effectually distributed instead of being allowed to enter the boiler at one spot, which might be injurious.

The boiler is also furnished with a damper and tackle, ashpit-frame, and foot-plates, placed just in front of the boiler. Flue-doors are placed in front to give access to the flues of the boiler.

After the current of flame and hot products has passed through the boiler, it is split and passes round the sides; then it dips and passes underneath the boiler, and thence past the damper to the main flue.

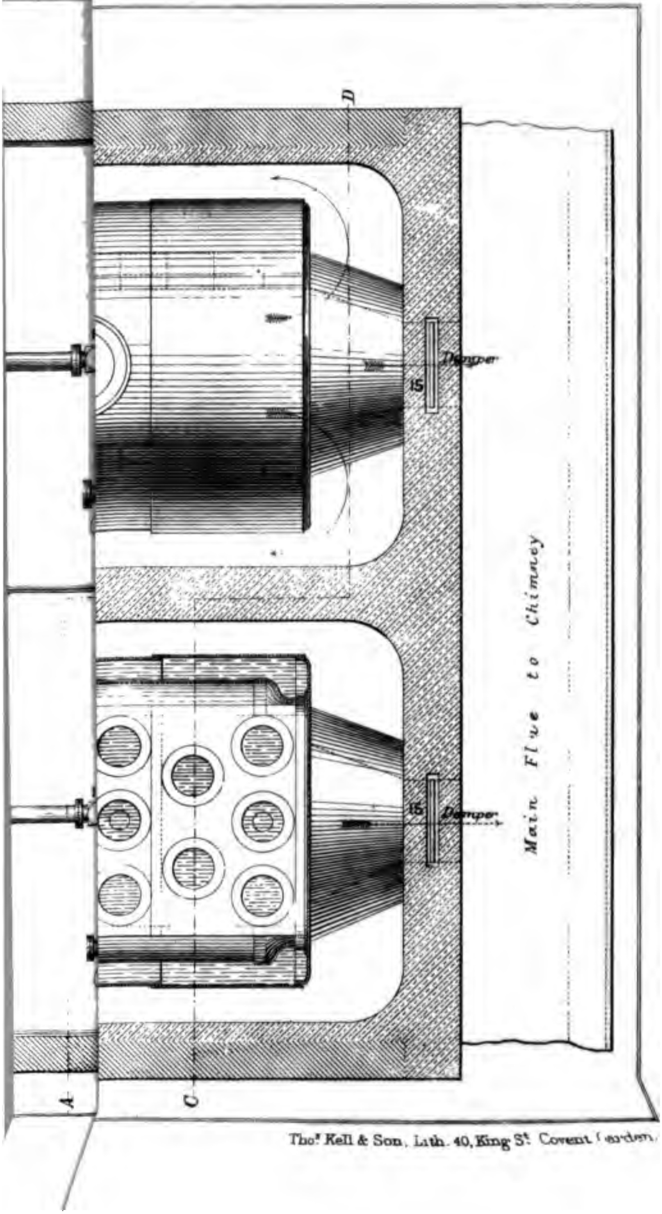
The method of conducting the gases along the sides first, and afterwards along the bottom, is found to act much better with the Galloway boiler than the reverse order of passage—under the bottom first.

The boiler is set upon lumps, which are better and more easily fixed than fire-brick.

The setting of boilers has been much improved. There was a time when the flame in the side flues was allowed to impinge upon the plates of the boiler above the water-line. The plate, in consequence, was liable to become overheated to a dangerous degree, and weakened by the sudden access of occasional draughts of cold air, by which their temperature was suddenly and unequally reduced. All the heating surface in the flue—that is, the surface of the boiler which is exposed to the heated gases—should be below the water-line, with a margin of safety. The plates at the side, when they are exposed to frequent changes of temperature, must inevitably become a source of danger.

Another barbarous practice is to set a boiler upon a bed of wet brickwork and mortar, on a wet foundation, exposing the plates to corrosion as soon as the boiler is

Plate IV



Thoˢ Kell & Son, Lith. 40, King Sᵗ Covent Garden.

set to work. Corrosion under such circumstances never ceases in the work of destruction until it has necessitated the boiler being lifted off the brickwork and patched.

Formerly, boilers were supported on the centre by a mid-feather of raw brickwork, so that water from a leaking rivet or joint would naturally run down the boiler side and assist the corrosive agents in their destructive work in the neighbourhood of the plates which rested on the middle support. The evil was alarmingly intensified by the extent of the brickwork in width and in length, touching a large area exposed to the work of destruction. This deceitful agent worked in the dark. How was it possible for a man to examine what was going on under a boiler in the centre of an 18-inch brick wall extending to a length of from 20 to 25 feet? Is it surprising that boilers have suddenly *left off working*, and ascended, to bring down a factory with them in their descent.

Boiler after boiler explodes, whilst the causes of explosion can be clearly traced. Little by little, alterations and improvements are made, which lead to a reduction of the number and extent of accidents by explosion. Much of the amelioration is due to the invaluable influence and the good management of boiler insurance companies. But all that can be done is not done; the men in charge of boilers should hold certificates of service and competency.

CHAPTER X.

DETAILS OF THE GALLOWAY BOILER.

Safety-valve, 3 (Plates III., IV., V.).—The invention of the safety-valve was one of the most important of any connected with the steam-engine. The invention is generally ascribed to Papin, a French physician and engineer; but weighted valves or plug openings were made before his time. Some of the ancient steam-deities were so fitted. But Papin did for the safety-valve what Watt did for the engine: he extended and improved it, with respect to the mode of employing it, by means of levers and movable weights; and thus he prevented the valve from being blown off its seat. He made one valve to do the work, or answer the purpose, of many, by regulating the pressure upon the one valve by weights. Practically, he was the inventor of the steel-yard safety-valve as an improvement upon the dead-weight or direct-weight valve; and so long as safety-valves are used the world will be his debtor. Many wonderful tales have been told about safety-valves sticking upon their seats until the boilers they were supposed to keep safe have either blown up or collapsed. It is possible for a valve to stick, it is possible that it would cause an explosion;

but the liability to accident can be almost entirely prevented by proper design, fitting, and management.

Safety-valves are either flat-faced or conical. The contact of the former may be termed a lid-seat, while the latter is a mitre-seat. Both are weighted, either indirectly by levers or directly by dead-weights or helical-springs. Sometimes the dead-weight is attached to the end of the valve-spindle, and it hangs of course inside the boiler; but dead-weights have a nasty way of occasionally becoming detached, and then away goes the valve through the roof of the engine-house, followed by a discharge of steam and water, which prevents any one driving a wooden plug into the hole until the boiler becomes nearly empty. Both flat valves and mitre-seated valves are either guided to their seats by inside wings or by central stalks. Central stalks or spindles are apt to get bent by the accident of falling from a bench, or from the boiler, on to a stone floor. The injury is not detected until the valve is returned to its place and the steam is seen to blow "through" much below the boiler pressure. The cause may remain a mystery until all the steam is blown off from the boiler and the valve withdrawn. Then even it may be thought to be all right; but, when it is put into a lathe, between the centres it is discovered to be "drunk," that is, not perfectly straight. It may be only out of the straight by the thickness of a bee's wing, but steam is a gas, and the seat of the valve must be closed all round by the face of the valve; otherwise steam will escape where there is the slightest defect. Central spindles have an inherent defect, and that is that they are liable to stick in the guide-hole inside the pipe below the seating, by dirt

working up between the spindle and the sides of the hole. In many instances, when boilers have been out of use for a time, the valves have been found as fast as a rock, by corrosion. The conical or mitred valve with three stalks or wings is universally acknowledged to be the better valve. It is seldom found to stick unless it is imperfectly fitted, which may arise from its being made too good a fit, and not being allowed freedom of action under a change of temperature, or of other working conditions. When it is fitted into a cast-iron seat, itself being brass, the relative contraction and expansion are not the same, and the valve is then apt to bind and to deceive; and therefore to become a thousand times worse than no valve. The valve, as well as its seat, should be of hard gun-metal. The angle for the cone should be 45°, and mitred not more than an $\frac{1}{8}$-inch in width for contact. Many valves do better and wear longer with a $\frac{1}{16}$-inch mitre. The disadvantage of having too broad a mitre face on the valve is, that when the valve is opened by the steam this penetrates or insinuates itself between the conical faces of the valve and its seat, and acts upon a considerably larger area of surface than when the valve is down on its seat. Then, as a consequence, the valve, once opened, will not drop again into its seat until the pressure is diminished below that which sufficed to lift the valve, which is supposed to be the initial blowing-off pressure. Besides, with a wide face, the valve does not cut the steam off so clean and so promptly when the pressure underneath subsides, as a narrow-faced valve does.

The lever of a safety-valve should not be unnecessarily long—not longer than is required for the highest

pressure at which the boiler can be worked, so that the pressure cannot be increased accidentally by any one. Whatever length the lever may have, the engineman, if he chooses to do so, can place additional weights on the lever, and so lead to such an increase of the pressure as to burst the boiler. It will be noticed that in the safety-valve on the boiler illustrated by Fig. 14, the lever is bent downwards. When a valve is directly held down by a straight lever, there is a tendency, when the lever is pressed down at the end with a spring or weight, to jam the valve by an oblique thrust, caused by the centre of contact being above the point where the thrust takes place, which is obviously avoided by bending the lever.

Safety-valves should be allowed to blow off once every day, when their condition and accuracy may be tested with a "Bourdon" gauge. They should never be fixed out of sight—inside a pipe, for instance—with the object of carrying the steam outside the roof. If the boiler cannot be worked so as to avoid blowing-off, the valves should go outside the roof as well, with a chain attached, so that the engineman can control them. Of course, there they are more exposed to the corroding influence of the weather outside, and as their place is on the boiler, it is better that they should be fixed there—removed as far as may be from the opening for steam to the cylinder.

It is a very useless act of enginemanship to lift a valve off its seat with a boiler full of steam, as it causes a great and instantaneous rising of water and steam in the form of a cone, towards the valve; and when the valve is suddenly closed the water reacts upon the valve as a fulcrum and drives back with great force to

the bottom of the boiler, the effect of which has been sufficient to cause an explosion in a weak boiler.

It is necessary that every engineman should be able to calculate the necessary weight to apply at the end of the lever to balance a certain pressure on the valve, so that he may have a kind of command over what is in the boiler. Such knowledge gives a man a higher estimate of his berth; and gives him an air of confidence such as knowledge only confers. After a boiler is reduced in strength through wear and tear, it is a common occurrence to reduce the pressure by shifting the weight, which is often done without any calculation whatever. But it is far more business-like to make a proper calculation. Examples of such calculations will be found at the end of this work; but it may be opportune here to mention that the principle of the safety-valve-lever is very simple, thus (Fig. 14):—

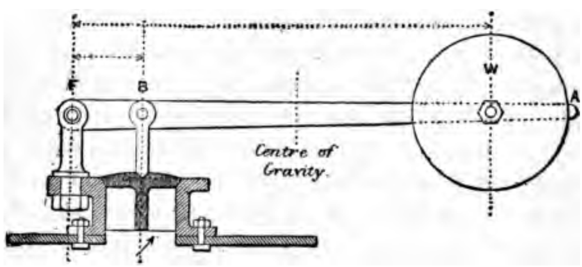


Fig. 14.—Safety-valve.

W is the power applied at different distances along the lever between A and B—the valve. The steam endeavours to leave the boiler by virtue of its elasticity, and constitutes the resistance at B. The greater the distance between B and F—that is, between the power and

the fulcrum—the greater is the leverage of W on the valve at B. If W and F are $17\frac{1}{2}$ inches apart, and B and F are $3\frac{1}{2}$ inches apart,

$$17\tfrac{1}{2} \text{ in.} \div 3\tfrac{1}{2} = 5, \text{ the leverage;}$$

then a weight hung on the lever at W would have an influence five times that of an equal weight at B, because it is five times as far between W and F as it is from B to F.

The proportion which the power bears to the weight or resistance is as the distance of the weight from the fulcrum is to the distance of the power from the same point. In a word, the power and the weight or resistance are inversely as their distances from the fulcrum.

Fusible-plug, 6.—Fusible-plugs are placed in the furnace-crown to prevent, or rather to give notice of, insufficiency of water in the boiler; but in many instances their value is annulled by their being too short in the inside of the boiler. It is obvious that if their length allows them to project into the water only a very short distance, they give alarm only when there is actual danger, instead of being a safe-guard in the actual sense of the word. A plug should give warning of danger long before the fire can injure the plate, and this can only be done by making the plug of sufficient length, and there is no reason why the end should not stand up in the water an inch or more above the fire-line. When plugs are too short they are liable to be covered with stony scale, and although the lead or alloy may be melted out the scale will prevent the water from entering the fire and raising an alarm of danger. By giving them a reasonable length they

have more chance of answering the purpose for which they are inserted in the plate. Although it is desirable not to have many holes in any boiler, in order to secure unimpaired the normal strength of the plate, yet it is a very desirable precaution to have more than one fusible-plug in every boiler.

Plugs should be fixed fore and aft the furnace-crown. In some instances, several small plugs are clustered together, fitted into a seating which is attached by rivets to the centre of the crown, but the accumulation of scale over this seating may render the whole of them practically useless. When a furnace is fitted with duplicate plugs, the investigation into the cause of the melting of one is much facilitated. The other remaining intact is a proof that the furnace-plates have not been overheated.

Many instances could be cited where much suspicion would have been averted and full confidence retained between an employer and an engineman if duplicate plugs had been used. We have duplicate gauge-glasses, and why not have the same laudable principle of security carried into the furnace?

A plug may be blown out through being worn out, and every engineman is aware that when the alloy gives way it causes much annoyance. This circumstance has caused very much inconvenience through the attendant not knowing how to act. But to prevent any unnecessary delay, the discharge of steam and water should be temporarily prevented by driving a wooden plug into the hole: this is attained by providing an iron rod of sufficient length capable of conveying the plug to the hole. It is a ridiculous idea to stop a mill or a locomotive simply because a hole half-inch or less in diameter

cannot be plugged for an hour or two, until the plug can be properly restored.

Care should be taken to renew a lead plug as soon as possible after it commences to leak. It may last for weeks and not give way; but the evil is that it leads to the wasting away of the plate about it, and in time necessitates a patch, the plate having become dangerously thin. Now a thin plate above the fire is in the most dangerous of all places about a boiler. The weakest part of a boiler should be the tubes, for a very plain reason. When a plug gives way the damper should be closed and the fire damped with green coal, so as to prevent an increase of steam which will follow by an induced current of air following the escaping steam made by the water being instantly evaporated as it comes in contact with a large body of fuel. These plugs often become dangerously softened before they reach the temperature at which they are destined to give way, and then they blow out. The occurrence is not always evidence of the furnace having been overheated. If they blow out when the boiler is full of steam, just close upon the normal pressure, very often the steam will suddenly rise and lift the valve, to the alarm of the engineman, whose attention is then doubly fixed upon the coincidence of the circumstances—plug blowing out, and steam allowed to escape into the fire; and the safety-valve allowing escaping steam to fill the engine-house. He naturally thinks she is going to burst, and flies to the pump. The sudden rise of steam occurs in the boiler through the pressure of steam being suddenly diminished; and the water round the plug-hole being put in a state of motion, the steam escapes out of the water into the steam-space.

Floats.—This class of gauges is fast going out of use. It consists of counter-balanced weights; the weight in the boiler is frequently a stone which floats on the top of the water, by the difference between its specific gravity and that of the water being counter-balanced by a weight outside the boiler. The two are connected by a wire suspended over a pulley. The wire works through a stuffing-box in the shell of the boiler, and the rise and fall of the water is shown outside by the position of the weight hanging by the side of the pulley.

It has many defects and requires well looking after. Its cardinal fault is that it is too sluggish, and requires more sensibility to record the position of the water with satisfaction than its principle will admit of. The varying positions of the water are not brought home to the attendant with such force by the float as by the gauge-glass. Then, again, the wire, when of iron, soon becomes oxidated and works in the stuffing-box with an excessive degree of friction which is highly dangerous. Again, this wire, if made of copper, is liable to stick by being packed too tight; and there is, further, the possibility of the wire being damaged and bent. Should it break, the business is all over until the steam is blown off, the manhole-joint broken, and the float fished up by a "nipper" lad. When the float is repaired, there is the joint of the manhole to be re-made; and by the time everything is ready to start again, the accident has cost a sovereign. Nothing of this kind takes place with gauge-glasses, which make a neat and certain register, without any inconvenience whatever.

When floats are in a leaky condition at the stuffing

box—and it is scarcely possible to prevent their leaking, for any length of time—the water and the condensed steam fall on the boiler, and trickle down by the side into some quiet cranny, so deep down under the boiler as to be out of sight—that means, in many cases, out of mind until the boiler gives out by corrosion. "Gauge-glass indeed!" said an engineman; "I prefer a float. Look what a box you would be in if a gauge-glass *bosted* in the night," continued he, with a knowing wink, which implied that that was a clencher. But gauge-cocks can be closed at night, and should be closed. Is any reliance to be placed in self-acting water regulators? None whatever; they soon become defective and worse than useless. They are generally worked in connection with the float, by means of cocks and valves; but they soon get out of order, and they leak, especially if the water is at all brackish or hard.

But the worst feature in the float is that it gives the boiler attendant an idea of security—when, possibly, there is no security at all. When a man knows that the water-level in the boiler regulates itself he is very easy about it, and he does not give the proper degree of attention to the varying height. There is nothing like keeping an engineman in a state of intellectual activity. He is all the better for it, and he knows it, and is ready to acknowledge it.

There is a report about that the enginemen of the present day would be completely lost if they had to do the intellectual part of what was performed by men years ago, both in stationary-engine working and locomotive working. The machinery is so nearly perfect that the work that is required to be done is the

same over and over again, until the man in attendance becomes a machine himself. But if a break-down happens, be it the bucket of an air-pump, or a foot-valve gone, he is not sure exactly what he is to do. Many men cannot act on an emergency—some men can.

The Steam-Pressure Gauge (*Bourdon's Gauge*), 4, is constructed on the principle that a hollow elliptical metal ring will uncoil itself by its elasticity when the pressure which is applied to it by the steam admitted internally is withdrawn. The construction is this: A hollow brass hoop of an oval cross section (thus ⬭), into which the steam passes, is secured at one end to a brass plate, which is fitted over the steam entrance to the gauge, the joint being made steam-tight. The other end, which is closed, is attached by means of a small arm to a toothed sector, which is geared into a small pinion upon the spindle to which the index-pointer is attached. The steam entering the hoop causes the end which is attached to the sector to move outwards from the centre; this causes a corresponding movement in the pointer, transmitted by means of the arm, sector, and pinion; the movement continues as the pressure of the steam increases.

The hoop, arm, sector, pinion, and frame, to which they are hung, are all of brass. The use of the inverted siphon-pipe is to collect a small quantity of water, so that it may act as a cushion between the steam and the working parts of the gauge; also to prevent injury, as the steam permeating the gauge would in time spoil its action, loosen the enamel from the dial, and also dim the glass so that it would become unreadable and unsightly. The cock which is placed at the lowest part of the inverted siphon-pipe is designed to draw

off any water which may have collected in it; if the water was not drawn off it would rise into the gauge, and the steam pressure would in consequence be incorrectly indicated. The steam-pressure gauge does not indicate the total pressure of the steam, but the net pressure above the atmosphere. The steam pressure is measured from the pressure of the atmosphere, that is 0, or zero, on the gauge. When the index of the gauge shows a pressure of 50 lbs. per square inch, it requires 15 lbs. atmospheric pressure to be added to the 50 lbs., making 65 lbs., to give the total pressure in the boiler. All pressure gauges should be provided with suitable stop-cocks to shut off the steam from the boiler, so that the gauge can be taken down and repaired. When it is put in its place, the bend in the pipe should be filled with water, which transmits the pressure of the steam to the spring at a low temperature; and the communication with the boiler should be opened carefully, so that the sudden impulse of the steam may not break the spring in the dial.

Every boiler should be fitted with an independent steam-gauge, fixed so that it can be readily seen by any one entering the boiler-house.

In frosty weather, the water in the tube is liable to be frozen, and the tubes require to be lapped with spun-yarn or some other non-conducting substance. The owners of steam-boilers should provide a check-gauge to detect any recklessness or oversight on the part of the engineman, by erecting an alarm pressure gauge, by means of which an accurate and faithful record of the boiler pressure may be rendered in the office.

It is fitted with an alarm-bell and can be set to any pressure, and so soon as this pressure is reached the

bell will ring. A large saving of fuel can be effected by adjusting the ringing pressure below the blowing-off points, and indirectly save unnecessary straining of the boiler either by over-pressure or by intermittent expansion and contraction, as it registers the pressure at any moment. It is especially useful where the engine is required to run as uniformly as possible. It incites those in charge of engines to the utmost care and vigilance, by furnishing them with a correct account of the result of their efforts to work the boiler as nearly to one temperature as possible.

Low-water Alarms.—Pinel's water-level indicators, acting by magnetic force, as constructed by Messrs. Lethuillier and Pinel, have given satisfaction; but they are indirect and delicate in action.

Duryea's electro-magnetic low-water alarm, on the contrary, is positive in action. It provides for the sounding, with certainty, of a call or alarm at any distance from a steam-boiler, when the water falls below a given level. The circuit-closing apparatus is enclosed in a tube fixed on the front of the boiler; and it stands, when in readiness for action, charged with hot water. If, from any cause, the water in the boiler falls below the proper level, the apparatus becomes charged with steam, which fills the chamber previously occupied by the water. The enclosed mercury, subject to a greatly increased temperature, is expanded, and it rises; and, coming into contact with a platinum wire suspended above it, completes the electric circuit, and sets the alarm-bell ringing. The ringing continues until such time as the water in the boiler has been brought up to its proper working level, and the tube becomes recharged with water. With the lower tem-

perature of the water, the mercury is lowered in temperature, and it sinks accordingly. The electric circuit is broken, and the alarm ceases. The alarm is conveyed by wires to the manager's office as well as to the engine-room.

Mercurial Gauge.—Where a "Bourdon" gauge is not used, some boilers are provided, as a check upon the safety-valve, with a U-tube (Fig. 15), containing mercury, open at one end to the atmosphere, and at the other end with the steam in the boiler. This gauge is only employed when the pressure is a few pounds above that of the atmosphere, and it requires careful using, otherwise the mercury may be blown out. There is not any danger attending it, as the bore in the tube is too small to allow of any sudden reduction of pressure. Steam is admitted from the boiler by the pipe *c* and presses upon the mercury contained in the tube M *b m*. Each 2 inches of rise is equal to 1 lb. pressure above the atmosphere, which has access to the top of the mercury by the open end of the tube. A line from the float in this tube passes over the pulley *p*, and

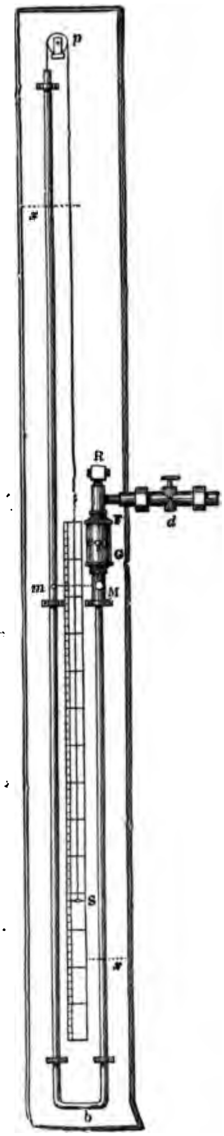


Fig. 15.—Mercurial Gauge.

is attached to the index S, to show the variation of pressure on the annexed scale. M, *m*, are openings fitted with suitable screws, which can be removed for the admission of mercury, which is poured in, until it shows itself at M, *m*, in each limb of the siphon. When these two holes are screwed up, the screw R is withdrawn, and a small quantity of water is poured on to the top of the mercury and the hole is screwed up. The water is provided in order to prevent the mercury from being oxidised by the steam.

Vacuum-Gauge.—This gauge consists of a case, about seven inches in diameter, with a dial-plate in front. Inside the case, and communicating with the condenser by means of pipes, there is a bent hollow tube, oval in section, the other end of which is closed air-tight, pointed off and attached to a sector which works into a small pinion, the spindle of which carries a pointer working against the dial in front. In the steam-gauge the pressure of the steam within the tube tends to straighten it; but in the vacuum-gauge the pressure of the atmosphere outside of it tends to compress or bend it, and thus move the pointer, which indicates the amount of exhaustion or vacuum.

Pressure in the Condenser.—The vacuum-gauge, like the steam-gauge, does not of itself indicate what *pressure* there is in the condenser. To find out the amount of *back-pressure* the difference between the reading of the vacuum-gauge and that of the barometer must be taken. Thus: Vacuum by gauge $26\frac{1}{2}$ inches, barometer 30 inches, then 30 inches $-$ $26\frac{1}{2}$ inches $=$ $3\frac{1}{2}$ inches, and this gives $1\frac{3}{4}$ lbs. per square inch, the absolute pressure in the condenser.

Barometer Gauge.—This instrument is employed for

the purpose of ascertaining the pressure of the atmosphere. It was invented by Torricelli, to solve the problem respecting the rising of water in a vacuum. It consists of a graduated tube of glass about 30 inches long. The tube is first filled with pure mercury—one end is sealed—and inverted with its open end in a cup also containing mercury. The pressure of the atmosphere upon the mercury in the cup prevents the mercury in the 30-inch tube from rushing out, and hence it is that the atmosphere is equal to supporting the pressure of a column of mercury 30 inches high, or, what is the same thing, a column of water 34 feet high. In the construction of the barometer, the principal object to be attained is a perfect vacuum in the upper part of the tube. To obtain this, the tube must be made perfectly free from moisture; it must have a bore sufficiently large to render the influence of capillary attraction insensible; the mercury employed must be purified by distilling it, when a portion may be put into the glass and boiled in it. Then more mercury is introduced and boiled in the tube; and so on until the tube is full, and the whole contents boil. Thus the air in the tube is got rid of as each portion of mercury is poured in. The tube should, in fact, be a little more than 30 inches long, so that when it is inverted, as already described, the mercury will adjust itself to the precise height (30 inches) by flowing out of the tube into the cup, and then but a small vacuum will be left in the top of the glass. We learn from the fact of the air supporting the mercury in the barometer that the normal pressure of the atmosphere is 14·75 lbs. per square inch, or in round numbers 15 lbs. A species of barometer is sometimes used as a vacuum gauge. It consists of a U-tube con-

taining a portion of mercury in both limbs. When the instrument is connected with the condenser in action, the mercury rises in one limb and falls in the other. In such a gauge, an inch of rise or of fall must be read as double the gain or loss, when compared with an inch of the straight one. The graduations in the common steam-gauge and the common vacuum-gauge are marked from atmospheric pressure; the one upwards, the other downwards.

The steam-gauge shows the pressure of the steam only, and therefore we must add the pressure of the atmosphere (15 lbs.) which is shown by the barometer to give the actual pressure within a boiler; the vacuum-gauge shows the pressure of the atmosphere below its normal pressure, and when it has been so rarefied as to be incapable of supporting 30 inches of mercury. The air may be so reduced as to form a perfect vacuum; although this cannot be accomplished in a condenser containing even the slightest amount of vapour.

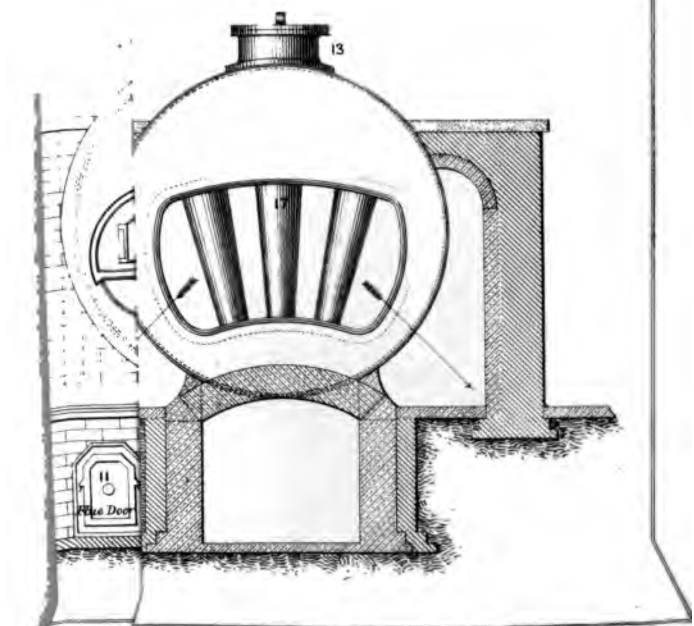
Vacuum is expressed as so many Inches.—Gauges are graduated to correspond with a column of mercury 30 inches high, which balances the weight of the atmosphere, and is equal to 14·75 lbs. or 15 lbs. Suppose that there is a vacuum of 20 inches. That would signify that the pressure of the atmosphere above the pressure in the condenser would support a column of mercury of 20 inches vertical height. To find the pressure of vacuum, subtract the reading of the vacuum gauge from the indication of the barometer. For instance, 20 inches vacuum = 10 lbs.; 30 inches vacuum = 15 lbs. Then 15 lbs. — 10 lbs. = 5 lbs.

Thermometer.—This instrument is used to ascertain the temperature of water or other hot bodies. The

Plate V

GH A

GH C. D.



Thos Kell & Son Lith 40 King St Covent Garden

thermometer was invented by an unknown author in the seventeenth century, and improved by the Florentine academicians. It received subsequent ameliorations at Sir Isaac Newton's hands.

This gauge is partially filled with mercury, like the barometer; but, unlike the barometer, it is close at both ends. The bulb and a part of the tube contain mercury, the rest of the tube is vacuous, and affords space for the expansion of the liquid. A graduated scale is attached to the tube to indicate the expansion of the mercury. Mercury does not take the solid form until it is cooled 39° below 0° Fahr., and it boils at a temperature of 650°. This extreme range of fluidity renders mercury a capital register. In the Fahrenheit thermometer, used in Britain and America, the number 0° on the scale corresponds to the greatest degree of cold that could be artificially produced when the thermometer was originally introduced. The freezing point, 32° F., corresponds to the temperature of melting ice, and 212° F. to the temperature of pure boiling water—in both cases, under the ordinary atmospheric pressure, each division of the thermometer represents 1° Fahr., and between 32° and 212° there are 180°.

CHAPTER XI.

STARTING AND WORKING AN ENGINE AND BOILER.

BEFORE making a fire under a boiler, or starting an engine, it is necessary to know something of their condition. This implies a general inspection; and without making this the first point or leading duty, there can be no confidence, and everything must be left to blind chance, in the absurd belief in one's luck. Thousands of mishaps have occurred simply because an engineman expected to find an engine and a boiler in the same condition in the morning as when he left it over night, which is presumption.

What should we think of a man, the captain of a ship, leaving port without ascertaining if he would be likely to keep sailing after he made a start; without going round and exploring, under a due sense of responsibility; without entertaining the slightest concern about the inconvenience that might arise from having to stop in the Bay of Biscay because his cargo was packed loosely; who looked on the course of events as a fool's paradise?

If a responsible engineman sows anyhow—by halves, roughly, or unsystematically—he will be sure to reap accordingly. It is as true as gospel. If we read actual human life as we read books, we should learn the

lesson, and should store it in the memory for future use.

Inspection of the Boiler.—No inspection is worth the name that is not thorough, no plausible scheme will do as a substitute. The boiler-house is crowded with circumstantial differences. There are imperfections in construction, and there are growing imperfections, which for a time lie deep enough to weaken, but not deep enough to be detected casually. From the hour a boiler is set to work, it is acted upon by destroying forces more or less severe and uncontrollable in their work of deterioration. These forces may be distinguished as chemical and mechanical. In most cases they operate independently, yet they are frequently found acting conjointly in bringing about the destruction of the boiler, which will be more or less rapidly effected, according to circumstances often difficult to detect.

Breakdowns and failures of every possible description, like everything else, have their causes and their origin within reach of investigation. Perfect enginemanship may consist of numberless qualities and shining talents, but that engineman is perfect who has acquainted himself with the hidden dangers which lie latent in the machine, and stored the memory with facts and incidents bearing upon every mishap that can overtake him in the course of his duties.

The first thing that demands attention is the water in the boiler or boilers. The engineman should ascertain whether the level as it appears shows correctly the height of the water within the boiler, by opening the lower cock of the gauge-glass. If he is satisfied that the boiler is safe, he should closely inspect the cocks

belonging to the gauge-glass, as they are apt to become fast by the deposit of impurities from the water. The gauges for ascertaining the level of the water within the boiler are of various designs, viz. the brass cocks, the glass water-gauge, and the float. The brass cocks are of the simplest design, and they are of the ordinary description, plug and shell. They are screwed into the boiler, one above the other, to indicate the height of the water; the lowest is placed in such a position that so long as the water is visible in the glass it is not actually unsafe, although when this bottom cock is opened and no water appears the boiler is in danger. The second cock, the one above, is usually placed at the best working level of the water. The third cock is placed higher up, and is placed in such a position as to show when opened an excess of water in the boiler, and how much water should be discharged from it. When the water is below the level of either of theselast two cocks, the fact can only be known by opening them and allowing steam to issue.

The glass water-gauge was introduced by Mr. Napier. It is a simple contrivance, by the use of which the necessity of employing gauge-cocks is avoided. There are two cocks communicating with the boiler and with a vertical glass tube of sufficient strength, with only a small bore ($\frac{1}{8}$th), to enable it the better to withstand the force of the steam. The cocks being opened, and in communication with the boiler, by a principle in hydrostatics that the surface of all water in different vessels in free communication with each other is at one level, the water rises in the glass to the same height as it is in the boiler. When the boiler contains steam it is very necessary to see that both cocks *are* in com-

munication with the boiler. For instance, if the top cock was not open, and the bottom cock was open, the weight of steam on the water within the boiler would push the water up the glass to the top, or would at least only be prevented from doing so by the air above the water within the glass tube. Therefore, when enginemen test the water by simply opening the test-cock on the waste-water pipe, it does not give positive evidence whether the glass is working right or not. To show the level correctly, the upper end of the glass must be open to the boiler as well as the lower end, so that there may be the same pressure of steam on the water within the glass as there is within the boiler. If there is the slightest difference it will cause a higher level of water to be seen in the glass than what there is actually in the boiler. It is then necessary that the steam-way and the water-way should be kept properly opened. This is troublesome when these passages are small. They are generally about $\frac{1}{4}$ of an inch in diameter; they should be at least $\frac{3}{8}$ to $\frac{1}{2}$ inch.

Float.—This is a simpler instrument than a glass-gauge, but it has many defects, and liable to stick, either through being packed too tight or becoming oxidated, but its greatest defect is its sluggishness and want of sensibility. By inspecting these cocks as soon as he arrives on duty, an engineman in no small degree has secured not only peace of mind but a safe boiler to work with—at all events to start with, and it is an old saying and a true one, that a good beginning makes a good ending.

The next object of notice is the pressure-gauge. The boiler may be safe for water and unsafe with an excess of steam. A glance at the gauge should show what

pressure of steam there is in the boiler. Now, it is possible to make the inspection we have noticed and yet miss an important point, and one which is most likely to teach an engineman something he could not otherwise discover. When a boiler is left on over night it contains so much water; and the next morning there is not quite so much, owing to the water having fallen in temperature. During the period that a boiler is perfectly tight and sound, the amount of water said to be lost never varies; but if the boiler is not sound, but leaks, either in the flues or the tubes, the amount of water which has run off from the boiler through the defective joint or fracture in the plate should be a warning to the engineman the next morning when he inspects the water-level. By this means he may be apprised of a rent or a loose rivet long before there may be any absolute danger at hand, or before he can hear the rivet leaking. Such painstaking does not cost much every morning, but it assists an engineman to obtain a clue to what is going on in the dark. In the full persuasion that the boiler is leaking somewhere, he timely seeks to apply the remedy.

Fire-Grate.—The available quantity of heat that can be produced from a ton of coal depends upon the condition of the grate in which it is consumed. Taking coal of superior quality and the grate in an inferior state, the efficiency of the coal, in water evaporated, may fall twenty or even thirty per cent. The type of grate for the best service is one with a good bridge, not too far from the door; bars of an equal length, and not too wide apart, and an ash-pit void of ashes. It is the practice of some enginemen to pull some bars out in

order to drop the fire; but it is liable to many objections, and the greatest objection is that the fire can be cleared or withdrawn without doing so. When such work is required to be done, the refuse should be drawn into an iron wheelbarrow, and deposited outside the boiler-house, and slaked with water. Carelessness on the part of the fireman in not keeping the bars well covered and forcing the fire at another place to make up for it means a loss. It is no exaggeration to state that boilers and furnaces can be made, by mismanagement in the boiler-house, to blaze away fifty per cent. of the fuel without any advantage.

The amount of heat lost by the hot ashes may range considerably when their condition is unsatisfactory. In a large factory with limited boiler power, all the heat is wanted, and where large cinders can drop through the bars a large quantity of cold air can go through into the fire.

It is the practice in some places never to renew fire-bars until a new whole set is wanted. Day after day some hundredweights of coal are wasted for the sake of the system. That system is best which saves fuel.

The safety-plug, or lead-plug, in the boiler, or boilers, should receive its due share of inspection; and to guard against any mistake being made it should, when the boiler is empty, be withdrawn from the plate, and, if necessary, refilled. Plugs are often left in until the lead or the alloy is perished in them and they stop themselves, and sometimes a factory full of hands. Three months is quite sufficient time for a plug to be left in without renewal of the metal. By inspecting plugs every morning, due notice is obtained of their disposition to break. Leakages should be stopped at once, as

leakages lead to corrosion, and to destroy the plate around the hole.

It is important that the blow-off cock should be in good working order, working freely and conveniently in its position without leakage. With a tap one may be pretty sure when it is shut properly. With a conical valve, working with a wheel or a screw, leakage is not so easily detected. All valves of this description should be fitted with indicators to show when they are quite shut. Many a boiler has been ruined through the water escaping noiselessly out of the boiler, in consequence of a blow-off valve not having been screwed quite down upon the seat.

The safety-valves upon the boiler should be clear to the view, not boxed up or placed inside a pipe, up which the steam escapes to the atmosphere. This is only an inducement to blow off steam. The practice of wedging down the valves should never be countenanced. It is also a favourite dodge, to hold the steam in the boiler, to pile some weights on the lever of the safety-valve, and although it is not so wicked an act as wedging it, still it is the right way to blow the boiler up. By an inspection of the lever the practice may be detected. The valve should be allowed to blow off, in order to test its correctness with the pressure-gauge; but with moderate care it may be kept quiet for the rest of the time. When a safety-valve is blowing off, and the engine is at work, the boiler primes.

The stop-valve on the steam-pipe should be opened very gently, to give the metal sufficient time to expand; and steam should be allowed to pass it with equal care, in order to warm the pipes gradually. By suddenly

turning on the steam, a stop valve-box was burst, not by steam pressure, but by the expansive force of heat unequally applied. Great care should be taken in opening all valves in connection with boilers, so that the pressure may come steadily on the pipes and cylinder; as, if there should be water in the pipes, the steam may drive it against a bend with sufficient force to split it. The same care is recommended when shutting off a stop-valve. A fearful explosion once occurred by shutting a communicating stop-valve too suddenly. Two boilers were opened into a third to blow out the water, its own steam having fallen too low for the purpose; when this was done the top-valves were closed, and both boilers blew up. The whole force of the steam was stopped in its motion, and the recoil from the valve struck back forcibly into both boilers and burst them. The same recoil takes place when the flow of water is suddenly stopped by a cock or valve. An engineman had been blowing down a boiler, but after doing so he found that he could not shut the cock on the boiler; he shouted to his mate to shut the "blow-off," and the recoil of the water and steam forced a small oak wedge out of the cock, which had been left carelessly in the boiler.

Neither in starting nor in stopping engines and pumps should the flow of steam or of water be interfered with suddenly.

Experience proves how little notice the destructive power of sudden expansion receives amongst unthinking enginemen. They know practically that if hot water is turned into a glass, the chances are that the glass is cracked; but, unthinkingly, they turn steam into cold pipes, cold cylinders, and cold condensers,

and when these break, the cause is declared to be unassignable. The cause is the same—the sudden admission of heat into a cold vessel; the effect is the same—a smash.

Before starting the engine, it should be seen to be disconnected from the machinery it is intended to put into motion, or the machinery should be ascertained to be fit to be moved. In either circumstance the engine itself should be examined, lubricated, and drained of condensed water.

In conducting an examination, it is well to remember that it is not big things, such as fly-wheels, cranks, and beams, which generally give out; but the smaller parts of an engine, such as bolts and nuts, keys, and tiny split-pins. The examination should be conducted systematically, and not directed to any particular thing that may happen to be thought of at the time. The whole of the engine requires to be examined before it is started. The examination should commence at the crank shaft.

Big-end.—The big-end brasses work best, wear longest, and knock least, when tightened up brass to brass. They are, otherwise, adjusted by means of a cotter, key, and a set-pin. When this plan is followed, the cotter and key are not fast. The set-pin used to keep them from shifting is liable to be slacked back by jars. But when the big-end brasses butt together, the cotter or the bolts for holding them can be driven to nip them tight, and thus may make a solid connection. When bolts are used, holes should be drilled longitudinally in them, in order to reduce their sectional area approximately to an equality with that at the bottom of the thread, so as to render them uniformly elastic.

Excentric.—The sheaves are generally of cast-iron, and the strap of wrought-iron, or it may be of cast-iron. The sheaves are keyed to the crank-shaft. The hoop or strap is always in two halves, held together by bolts and nuts. They should nip tightly together, because any slackness would interfere with the lead and the working of the valve.

Crank-shaft Bearings.—The brass bearings are fitted into plummer-blocks, which are bolted to the engine-bed. They give very little trouble, provided they are properly oiled. Should one, however, get heated and cut the bearing, or should it wear away faster than the other, it throws a very ugly strain upon the crank-pin —one likely to break it. As the bearings wear down, they are prevented from knocking by chipping a little off the upper brass, or by reducing the distance-piece between the brasses. But at all times the shaft should be maintained perfectly level.

Glands.—The most important point about glands is to see that they stand fair or square with the rods which are guided by them; and that there is sufficient packing in the stuffing-boxes to keep the steam from blowing through.

Trimmings.—The trimmings are generally made with worsted and a piece of copper wire; and they supply the various bearings with oil by capillary action. The trimming is made by placing the worsted of the requisite thickness on the middle of a straight piece of copper wire, which is then doubled and plaited several times to bind the worsted just sufficiently to hold it. The trimming is then placed within the siphon-pipe and pushed down into a position just clear of the axle, whilst the ends of the worsted lie in the oil.

This trimming will supply oil as long as there is oil in the cup; and, therefore, when the engine is stopped, the trimming should be pulled out of the siphon-pipe, and placed on one side in the cup. There are several circumstances to be noticed which, in the use of trimmings, operate disadvantageously.

The trimming may be too tight in the siphon-pipe; the cotton may be choked with tallow; the cotton may be wet or worn out.

Oiling.—The piston-rod packing is exposed to the heat of the steam; and, therefore, it should be lubricated with tallow, likewise the cylinder and the slide-valve spindle. Main bearings, such as those of the crank-shaft, the beam-centre, the crank-pin, and the excentric-hoop, demand special attention; for the renewing of such bearings, when destroyed by neglect, involves a considerable loss of time and money, to say nothing about the vexation. Amongst other points, there are the cross-head and guide-rods of the pump, which should be swabbed with oil: oil is better for the purpose than tallow, and the pump-top may be kept clean. The pump-gland requires no lubrication other than that which is effected by the passage of water.

Geared-wheels may be kept cool, and the wear reduced to a minimum, by using a lubricant composed of a mixture of black lead and tallow; which also keeps them from making the peculiar squeaking noise, which arises from their being allowed to run dry.

Another thing requiring attention is to see that air can enter the siphon-cups. If it cannot, lubrication is arrested. By the access of air, atmospheric equilibrium is maintained.

When the boiler and the engine have been thoroughly

overhauled, and the engineman has satisfied himself that there is nothing in the way of the engine or the gearing—as blocks of wood thrown about, or waste amongst the teeth of geared wheels—he should proceed to expel the air and condensation-water in the cylinder. In a non-condensing engine this is effected by opening the cylinder-cocks and admitting a little steam into the cylinder until it is warmed and dried. The operation is very simple; but it is not so simple for a condensing engine, and, therefore, we will confine ourselves, as the operation is more complicated, to the starting of an engine such as requires the most skilful enginemanship. The first operation is to admit steam to the jacket which surrounds the cylinder; the steam warms the cylinder, and when it issues sufficiently dry through the waste-pipe into the condenser, getting rid of all the air and water in the cylinder and steam passages, then the blow-through valve may be opened to eject any air or water that may be in the condenser.

If the blow-through valves and the injection-valve are closed, the result will be a vacuum, shown on the gauge. If not, then the process is repeated until a vacuum of 5 inches or 6 inches is obtained. This amount of vacuum is ample, and it may be attained without incurring the risk of heating the condenser or the air-pump bucket. If the bucket be suddenly expanded by heat, it becomes fast, and the result is likely to be a bent air-pump rod to begin with. These preliminary operations are effected by working the hand-lever, whilst the excentric-rod is disconnected.

All going well, the engine is moved round a few revolutions by hand, by means of the starting or hand-lever; or the hand-lever is used to move the slide-

valves up and down, to distribute steam on both sides of the piston. By this operation the engine is set in motion. Great care must be taken that the engine does not stop on the centre. With a large engine this incident happening is not creditable; nor is it a comfortable performance to pinch her off. The crank may be in the position shown in Fig. 16, when the end of the excentric-rod should be dropped into gear. The starting bar should be at the same time taken out of gear; if not, it may knock a man over before he is aware of it. Much care is needed at first, especially at starting, to see that the engine is not flooded with water. If the injection is over done, the air-pump bucket may not be able to clear the condenser, and the water rising into the cylinder may break the beam in halves.

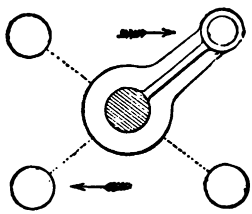


Fig. 16.—Position of the crank at starting.

To put in a gauge-glass.—When a gauge-glass breaks, another should be at hand already cut to the required length. The length should be such as not to allow the glass to interfere in the least, either at top or bottom, with the passage into the boiler. The glass may be cut with a triangular file. First, wet the file, hold the glass tube with the first finger and thumb at the place where you wish to cut it; draw the file sharply and lightly two or three times backward and forward; if the file is pressed against the thumb-nail of your left hand, the file will be kept on the same place on the glass; the file will mark the glass. Take the tube, then, in both hands, the hands being an inch

or two on either side of the scratch, then attempt to bend the glass, and it will break across at the file-mark, which weakened the tube. Another way: the tube may be cut by inserting a small round file, or the end of one, within the bore, to the point where it requires to be cut, and then scratching it all round with the point of the file, keeping the file in the hole; break the piece off, by holding the tube still in the left hand and depressing the right. Hold the tube in a cloth, or a piece of waste. Very serious accidents have happened by pieces of glass entering the fingers. The power of sensation and use of a finger have been partially lost by such an accident. After all the old packing has been cleaned out of the sockets, blow the passages out by steam to clear them of broken glass, hemp, or india-rubber, and then put the glass into its place, taking care to measure again and see that it does not interfere with the passages into the boiler. Before inserting the packing a small piece of wood should be placed on the top of the glass tube, and held down by screwing the top nut round a few times; this will prevent the glass being lifted whilst the top is being packed. Accidents of a serious character have happened through the glass having being lifted up, when packing, so as to lap over the hole into the boiler. With the precaution noted above, such an occurrence cannot happen. The communications with the boiler should be opened gently, so as to warm the glass by degrees. If hot water or steam is turned on suddenly, the glass will snap by unequal expansion.

When a glass is burst, the water should be turned off first, and then the steam. When your hand is on the water-plug, the steam from the upper hole is partially

condensed before it reaches your hand. But if you shut off steam first, the escaping water will scald.

Priming.—This is caused by the lateral frictional action of the steam against the globules of water, as it is forced upwards to the surface of the water, and thereby putting in motion and drawing upwards much water, which is borne along by the energy and velocity of the flowing steam into the pipes and cylinder, just as a mass of nut-brown leaves lying under an oak-tree are borne along in the current of the passing wind. Such is the natural cause of priming. The principal occasion of priming is deficiency of steam-space in the boiler, and the want of a good head of steam. This deficiency is not always traceable to faulty construction of the boiler, but may arise from mismanagement. Steam-space can either be diminished or enlarged by adjusting the level of the water within the boiler. When a boiler is filled with water there is no steam-space, and its capability for supplying dry steam is practically diminished. In such a case the steam-space is limited to the interior of the steam-pipes and the steam-chest. If they have a cubical capacity sufficient to hold as much steam as will fill the cylinder twenty times or more, the evil of working with a boiler full of water is proportionately diminished, compared with the bad effects of small capacity in those parts. Steam-space is required to hold sufficient steam, so that in the discharge from the boiler to the cylinder the pressure in the former shall not fall in any considerable degree, and that the steam-gauges shall not exhibit any considerable fluctuation. Where there is only a short run of steam-pipes, the steam-space is absolutely confined to the boiler; and when that is so, as much room as possible

should be found for the steam above the water. The best preventive of priming is a good head of steam.

The water in the boiler has always a tendency to rise with the steam near the opening for steam to the cylinder. This tendency exists in proportion to the fluctuation of pressure at each stroke of the piston, which is caused by the steam moving from the steam-chest into the cylinder, and the steam in the water rising to the top receiving a sudden impulse, to take the place of that withdrawn to work the engine. This impulsive motion signifies collision and confusion in the mixture of steam and water. Instead of there being a uniform rising of steam, and a uniform falling of water to the hot plates, there is an intermittent action — explosive violence alternating with calm inaction. Steam-space prevents this, if due care is taken to keep the pressure up.

Steam, when used to produce power, varies in value according to the pressure. The greater or less elasticity of steam is not the effect of its density alone, but also of its expansion by the free caloric, or heat, which it contains.

The pressure in the boiler should be maintained just below the blowing-off point, and the throttle-valve least opened, so that the steam may be highly elastic, for in proportion to its elasticity so is the gain in mechanical effect and in economy of fuel; but when the pressure is allowed to drop, the head of steam is reduced, and instead of the valve cutting off at, say, one-third of the stroke, it must, in order to keep up the speed of the engine and machinery attached, cut off at half-stroke, and the fluctuation of pressure caused at each stroke increases the ebullition of the

water near that point of the boiler whence the steam is drawn. The ascending currents of steam which are disposed to fill the steam space are in most violent action, and they by lateral friction lift a large quantity of water in the form of spray. Not only so; when the induced current is sensibly felt in the boiler, particles of earthy and other foreign matter are carried up into the steam-pipes and conveyed into the cylinder, where, in conjunction with oil or grease, they cut at every stroke into the face of the valve and the cylinder. In boilers using dirty water, particular care is required to keep plenty of steam *waiting* for the cylinder; for if the supply is short, and if it is used as soon as it is made, it will certainly carry away with it the scum and dirt floating on the surface of the water, and the dome, pipes, steam-chest, and cylinder-ports will be plastered with mud.

Whatever system may be adopted for holding back the particles of water, no system succeeds, where the boiler-power is limited, like an internal perforated pipe fixed near the top of the boiler, and close to the supply-entrance to the cylinder.

The aggregate sectional area of the perforations in the pipe should exceed the sectional area of the pipe. By this plan the amount of spray carried off by the steam is minimised; and if it do not altogether prevent priming, it is an invaluable check upon such violent local ebullition as takes place when the steam is drawn from one point, and especially if that point is over the furnace. Sometimes a dome or super-heater is added, for the purpose of preventing priming; it simply increases the steam-space. In some cases the steam-space is increased with excellent effect by taking out

the top row of tubes, or even two rows; this improves the circulation of the water and free escape of steam, and instead of being a loss, by the decrease of heating-surface, it becomes a gain.

No amount of steam-space or of ingenious mechanical arrangement will suffice to regulate the action of the steam if there be not a thinking head in front of the furnace to insure regular firing. Some enginemen can work boilers well which others have given up as incurable primers; but there are enginemen and enginemen.

Now, a boiler is not always in the hands of owners who are willing to make alterations; and therefore an engineman who is equal to his work will, with a ticklish boiler, conduct the firing with great regularity. Any boiler can be made sensitive and hard to manage. Fire it on no system, feed it with water, just as the lead-plug is in danger, and fill it to the whistle, and your boiler will one day give a big kick. Irregularity of firing is easily prevented where there is a will. The smaller the steam-space, the greater the regularity that is required.

The rapidity of the ebullition occasioned by a small addition of heat may be witnessed experimentally by applying a piece of lighted paper to the bottom of a kettle containing boiling water. The heat will be rapidly taken up, and the ebullition will become most violent even upon so small a scale.

Ebullition consists in the forcing upwards of particles of water by colder particles: a due succession of such particles ascending and descending is necessary to take up the heat from the heated plates. The sole motive-power is the diminished specific gravity of the water

in contact with the heated plate. After ebullition has taken place for some time, the rising globules of water obtain great physical power, and the slightest addition of heat over and above that of the surrounding mass, causes the water to force its way upwards through that mass, thus putting in motion a body of water, the motion of which is continued by the induced current of steam flowing towards the cylinder. Hence, again, priming, caused by an injudicious excess of heat suddenly applied to the furnace crown plate, or tubes. Priming sometimes takes place by mixing waters of varying specific gravity. If greasy or soapy water is introduced into a boiler, the grease, surrounding the globules, resists the passage of heat, and they are able to retain the spheroidal state until they are heated to a much higher temperature than ordinary water requires for evaporation. When their evaporation is effected, it is done by force, and the steam inside the film of oil being, so to speak, overheated, rushes upwards when liberated, and meeting greased round globules of water, with reduced lateral friction, it puts all into motion, right and left, and priming becomes heavy.

As soon as priming commences all the drain-valves about the cylinder should be opened, the engine should be slowed down, all the feeds put on, and the furnace-doors opened until the water becomes steady in the glass. The furnace-door should only be opened in extreme cases.

There are several advantages in a liberal steam-space. When the steam-space is large in proportion to the volume of steam used in the cylinder—and the proportion of space should be regulated by this—the pressure of steam in the boiler exhibits no considerable fluctua-

tion, the pressure of the steam does not perceptibly fluctuate, as it is being drawn in intermittent quantities to the cylinder. In locomotive boilers, however, it is not an uncommon thing to see the needle of the pressure-gauge working or vibrating upon the joint when the steam is being discharged into the exhaust-pipe, through the cylinder, as fast as it is possible for the boiler to supply it.

In ample steam-space there is a provision against the results of any relaxation in firing, and steam is kept up with much greater regularity, and without any waste of fuel—unnecessary waste. Where the steam-space is cramped, the fire is generally urged by a strong draft, and the gases in the furnace are consequently hurried along the tube, or tubes, before they can part with anything like the proportion of heat which they are capable of transmitting to the water. The gases obtained by chemical combination in the furnace, or fire-box, part with their heat as they fly along the passage to the chimney. They possess a gradually-diminishing amount of heat, as they leave from the bridge, or tube-plate, until they unite with the open air. As they pass each inch of heating-surface, they give up a portion of the heat which they have in excess, in virtue of the excess of their temperature above that of the surrounding plates. But the proportion of heat given up depends on the time during which they are in contact with the cooler body, the boiler.

CHAPTER XII.

MANAGEMENT OF THE FIRE.

COAL; what is it? Three generations back Erasmus Darwin came to the front, and maintained that coal was formed out of ancient morasses and forests. Subsequently, full and accurate information was dispensed from the laboratory respecting the chemistry of coal; but the development of the principle on which perfect combustion is achieved, belongs to more recent times. Coal consists of decayed trees, which lived and grew to a hundred feet in height, and even more. From this it is justly inferred that this country was once favoured with a tropical climate.

At the feet of these gigantic trees, there grew gigantic ferns, and the roots of both were bedded in mud, which, in process of time, became mud banks, and then mud hills, formed by innumerable tides in primitive times. As these banks had once stood high and dry, then were buried during a succession of ages, so during a succession of ages they were left high and dry again. The finding of organic remains at the base and the apex of the coal rocks shows that their total submersion has taken place since the creation of animals.

The transition from the state of living woody tissue

to the mineral coal, does not admit of doubt, for the impressions of the leaves and stems of ferns and trees are clearly discernible in numerous instances in coal of a stratified character; but the precise conditions under which the decaying woody matter became so largely bituminised in its conversion into coal have been but imperfectly made out.

Practically, there is much around us that is intricate and mysterious, but much light has of late years been shed from out of the laboratory, which has, in more ways than one, given us to understand scientifically the elements with which we are surrounded, and their influence upon each other.

The chemical union of air with the compound mixture in coal, as we know it, was at one period an association that entered into few men's heads, and the conditions of the evolution of light and heat, by the contact of gases with each other, were outside the pale of popular intelligence. Combustion was for a long time held to be the disengagement or development of a certain air, supposed to have been contained in all combustible bodies, and to which the name of phlogiston was given, and those bodies which had undergone combustion were said to be dephlogisticated, or to have given out their phlogiston. This hypothesis was held in the face of facts at variance with it, for it was well known that metallic oxides formed by combustion increased in weight, which could not have been the case if combustion consisted in depriving a substance of one of its constituents. It was not surprising, then, that philosophers differed upon the point, nor strange that Lavoisier should have made the brilliant discovery that light and heat could be caused by oxygen

at the moment of its fixation with a combustible body.

Many elaborate analyses have been made by eminent men to ascertain the constituents of coal; and analysis shows that the principal ingredients are carbon and hydrogen. There are other minor ingredients: oxygen,

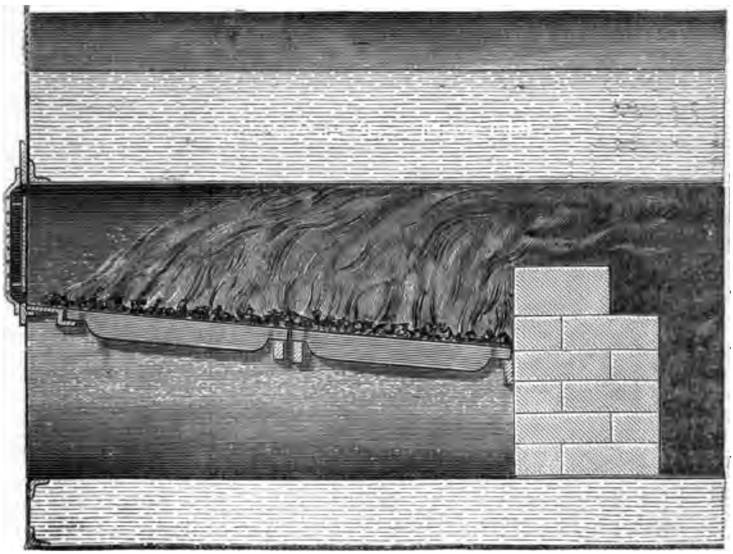


Fig. 17—Imperfect combustion.

nitrogen, sulphur, and ash, which determine the economical value of coal for raising steam; but, without detracting from the specific importance of these elements of coal, it may be stated broadly that it consists of 80 per cent. of carbon and 5 per cent. of hydrogen. In the natural state, these elements are united as a solid, but their characters and modes of entering into

combustion are very different. The hydrogen is the first to take fire, and it burns in a gaseous state; the carbon is combustible in a solid state.

The application of heat is necessary to start the process, and there is no stage, from the time the fire is lighted until it is practically giving out an intense heat, that does not depend for its advantageous effect upon two cardinal conditions, namely, saturation and temperature.

The natural law is that combustibles become saturated with oxygen in certain fixed proportions, to form certain chemical products of combustion; and that can be accomplished only when the right temperature prevails.

On the application of heat to coal, the fire at first may be seen to be nearly all smoke; this consists mostly of hydrocarbons, in which hydrogen is in combination with carbon. After the fire is sufficiently heated or ignited, or, which is the same thing, when the temperature is sufficiently high, and the fire-door is shut close, water—the product of combustion of hydrogen with oxygen—coloured with carbon, will be found in abundance about the furnace. Some persons, witnessing this natural result, not knowing the true cause, have ascribed it to the sweating of the iron. So long as the same temperature is maintained, and the same amount of air admitted, for every ton of coal, half a ton of water and more can be formed by this process. Now suppose that, by opening the apertures for air, all the smoke vanishes, then the hydrogen and the oxygen are receiving their proper quantity of air necessary to make combustion perfect. The furnace is now higher in temperature, and the proportion of air admitted is

greater in quantity, and so the conditions are such as are necessary to form carbonic acid.

Carbonic oxide is formed when combustion is imperfect, and carbonic acid when combustion is complete. If the air is deficient in quantity, large volumes of smoke pass away into the chimney. This

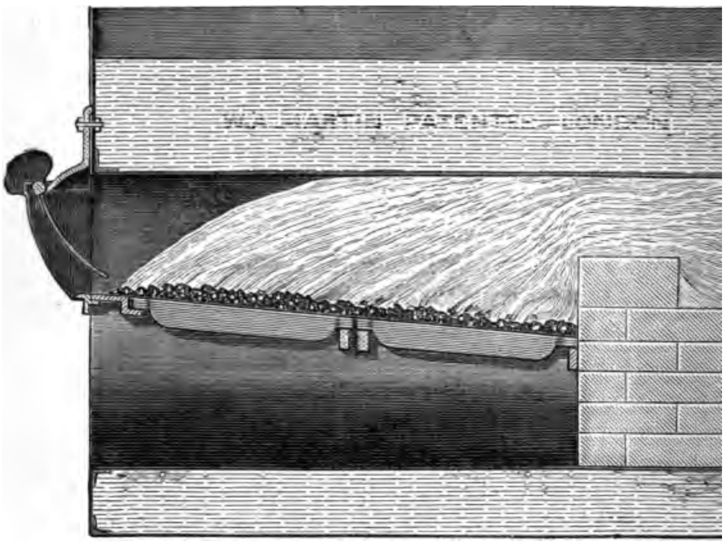


Fig. 18.—Perfect combustion.

smoke contains the distilled essences of the fuel, and, being heavily charged, it lounges on its way ; as they become cooler in passing through the flues, carbonaceous particles lodge there. People who do not know the real value of the carbonaceous matter, call it soot; it is, nevertheless, coal wasted. It is just as much coal, as iron-filings are iron. When air is supplied to the

furnace in sufficient quantity, the combustibles are all supplied with oxygen, and *then*, the carbon, which passed away in a state of very fine division as smoke, meeting with *its* amount of oxygen, at a sufficiently high temperature, it unites and forms carbonic-acid gas. We might call carbonic oxide an extractor of heat, and carbonic acid a giver of heat. A mass of fresh fuel thrown upon a bright fire extracts its heat, for the volatilisation of its gas from that fire, and the heat for a time is converted from the sensible to the latent state. A large volume of gas being generated, more air is required to reconvert the heat from the latent to the sensible state.

No better evidence of the necessity for supplying and intimately mixing air with fuel could be given than by the numerous plans which have been resorted to by smoke-burners. Such are split-bridges, Argand furnaces by dozens, air-boxes at the bridge, perforated plates at bridge, hot-air at the bridge, and jets of steam. Many of these plans are worthless *now*, but they mark the successive strides in the march towards the attainment of something better.

Many of the inventors were on the wrong track, and the work of the labourers in this branch of science has been comparatively unproductive, because they followed the popular fallacy—jumped in fact at the conclusion—that smoke, after it had left the furnace, could be ignited. Smoke must be *prevented* from forming as far as possible; but when formed it must be ignited in the furnace, or it will surely go up the chimney in the same condition. The carbon particles in the vapour of the smoke will not unite with the oxygen except at a high temperature. By air-boxes and like means, the

smoke discharged at the chimney-top was reduced, but it was not because the smoke was consumed. What was done was this: The cold air (at 60°) admitted at the bridge, on coming in contact with the heat there coming from the furnace, was suddenly raised in temperature to 1000°. When, in virtue of its increased lightness, the velocity of the draught was increased as between the bridge and the chimney or atmosphere vastly superior, as between the door and the chimney, before the smoke-burner put his patent in. The draught was improved by the newly formed current of air, whose velocity inducing a better quantity of air to enter the furnace at the door and up through the bars, produced a better mixture in the furnace of the gases; and the result was an improvement—less smoke, and a better result—*but* the smoke was not burned, as many thought it was, beyond the bridge in the tube. One of the most successful plans for inducing a current of air to enter the furnace at the door was invented by Mr. D. K. Clark. Jets of steam are introduced into the furnace above the door in combination with a supply of fresh air from the front, and are directed over the fire towards the bridge, by which the draught is considerably increased, the gaseous elements are thoroughly mixed, and combustion completed within the furnace. Provision is made for adjusting the supply of air. This plan is thoroughly effective as a smoke preventer. The steam jet, it will be seen, is the instrument to draw into the furnace, *by induction*, the necessary amount of air from which the combustibles could obtain the requisite quantity of oxygen to effect complete combustion of the gases within the furnace.

Grate.—As to the best proportions for the grate,

they depend upon the rapidity with which steam is withdrawn from the boiler; but, although this may vary, there is one thing about the furnace that should never be neglected; and that is, that the grate should be of a length just sufficient to insure a complete mixture of the gases before they pass over the bridge, and here the ingenuity of the engineer is required. If he finds the fuel is not burned perfectly, notwithstanding the plan of side-firing—of which more presently—he may seek for the cause either in the arrangement of the grate, or the management of the draught.

In many furnaces the grate is too long. With a very long grate—say, 6 feet in length—a material proportion of the combustible on the bars, especially at the back part of the furnace, passes away into the flues without having secured the proper quantity of air for completing its combustion. This defect arises from the fact of the fuel near the door seizing its share of the air, and the formation of carbonic-acid gas, which, moving forward in the direction of the flues, is arrested by the carbonaceous gases loitering in the neighbourhood of the back part of the furnace; and the result is, a second portion of carbon is added to the carbonic acid, and carbonic oxide is formed. If this carbonic oxide cannot find the oxygen required, together with the temperature to be reconverted into carbonic acid, it passes away necessarily as half-consumed gas, and rolls away from the top of the chimney in a dark cloud of smoke. Then, with an excessive length of grate, there is the difficulty of keeping it properly covered with fuel at the bridge. For, besides the difficulty of properly distributing the fuel at the end of a grate of considerable length, the fuel burns

away faster near the bridge than at other parts nearer to the door. With a shorter grate the fire is managed with less difficulty; the draught also is more nearly uniform, and is more active in consequence of the concentration of the current on a grate of less area. Hence, also, the combustion is more rapid, and the temperature in the furnace is higher, and smoke is more effectively prevented.

The fact is, many boilers are worked as hard as possible, and economy is out of the question. When the supply of air is imperfect, it is strikingly demonstrated soon after firing by the volume of smoke discharged, although the smoke gradually disappears. Hence it is that the opening of the door a little to admit an additional quantity of air above the fuel immediately after firing usually prevents to a great extent the formation of smoke.

Can smoke be prevented?—An opinion prevails amongst firemen that if by any means, either through the bars or through the doorway, air can get into the furnace, it will, as a matter of course, arrange itself, and mix with the combustibles in a manner suitable for perfect combustion. It is a mistaken opinion.

The prevention of smoke is only effected when the right quantity of air is admitted—no more nor less. Were there nothing else required—no more attention in the use of coal—than the combustion of the fixed carbon, that is the coke portion of the coal, combustion would be easily effected; but, in the combustion of coal, there is the gaseous element to deal with, to be generated and consumed. We will suppose ourselves at the front of a furnace containing a fire thoroughly burnt through, bright and cheery, whilst air is ad-

mitted through the fire-bars and above the fire. Now, what is in the furnace is as nearly coke as anything can be: it is the fixed carbon left behind after all the tarry matter has either been consumed or escaped as smoke. On a charge of *cold* coal being thrown into the furnace, it extracts heat from the fire, as a matter of course, or where would it obtain its heat? For a moment this abstraction of heat by the cold coal reduces the temperature of the furnace, and if the charge of fresh fuel is spread over the whole of the fire, it is sufficient in some instances to lower the temperature of the furnace to such an extent as to cause a boiler to leak by sudden contraction of the plates near the fire; and as this contraction is in its direction fore and aft of the furnace, it has a tendency to shear the rivet heads off and cause a boiler explosion, and if anybody examined such a boiler they would consider it was unexplainable, or put it down to electricity. Now, with the fresh charge a gas-generating process is set up, and large quantities of gaseous and inflammable material are given out, and unless there is an equivalent quantity of air allowed by the fireman to enter the furnace and chemically combine with them, they pass away and create smoke. The fact is, the furnace is precisely in the condition to receive air, as the relative proportions for complete combustion are wanting. What are escaping? The hydro-carbons, the very constituents of the coal which form flame, and are being carried away by the gases to be deposited on the surfaces with which they come in contact; and if the current is sufficiently strong, and the chimney not too high, they will ignite on coming in contact with the atmosphere, as may be seen in the case of

steamers, or locomotives at night. Because these gases could not find the air they require *in* the furnace, it is seen that, when they meet with it *outside*, they instantly combine with the air and ignite. A skilful fireman, with great exactness and calculated punctuality, after he has put on a fresh charge, regulates the air, and by bringing sufficient oxygen in contact with the minute particles of carbon ascending in the gases, their combustion is effected within the furnace, and the gases, instead of being coloured black with the minute particles of carbon, ascend on their way to the atmosphere invisible, and consequently no smoke is produced.

Thickness of the Fire.—Along the sides the fire should be deeper than in the middle, having a depth of from 6 to 8 inches at the sides, and from 3 to 4 inches at the middle. These depths will be found to give good results. Near the brick bridge, the depths should be slightly increased, in order partially to meet and deflect the current advancing towards the bridge, and thus somewhat to force the air into contact with the gases.

Shape of the Fire.—The "pancake" fire is made by shovelling the coals all over the grate, and requires no skill. So long as there is a bright patch of fire to be seen, the shovelling goes on until the light is put out. This is a barbarous and wicked practice; barbarous because it is behind the times, wicked because it may *burst* a boiler by cooling it too rapidly, and causing an enormous amount of contraction about the furnace of a dangerous nature. It was found by the use of a pyrometer, an instrument necessary for every engine-house, that a stiff charge of green-coal would lower

the temperature of an ordinary furnace 200° or 300° in a very short time. After the coals were well ignited the temperature would rise as much as 500°, and as the fuel became low the temperature would gradually decrease about 250° until the fireman charged again, when, as already mentioned, there would be another decrease. From this it is easy to infer that the variations which take place in all the different stages of combustion consequent upon the acts of charging, stirring, &c., have a serious influence upon the furnace-plates, and also upon the safety of the boiler; and that the sudden contraction caused by firing is as liable to cause a boiler explosion as a safety-valve jammed down or out of order. There are, probably, no fractures of such frequent occurrence as those found at the joints of the furnace-plates, and these fractures are most common from the holes to the edge of the plate in the outside lap. The fracture may not be very serious at first, but it gives rise to leakage, which is generally the alarm note calling the boiler-maker. The mischief is done by local contraction in the furnace, and about the bridge. It may be stated that expansion opens and contraction closes, but if this law is applied to a lap-joint, it will be found, if suddenly cooled in an expanded state, that a great tensile strain is put upon the outside plate of the lap; the inner plate extends away into the tube, and retains much, if not all its working temperature, and the result is it resists the contracting and pulling of the outer plate, and between them they endeavour to liberate themselves by shearing the rivets off; good rivets being strong, the rivet-hole is ripped open to the edge of the plate, and under such conditions it is the

contracting furnace-plate that is damaged, as a matter of course, because the temperature of the inner plate is comparatively unchanged. However good the boiler-work may be, the very best plates are soon rendered brittle, and are fractured through the rivet-holes, to the imminent danger of everybody, by bad firemanship. The pancake-fire is flat throughout, but the thickness is generally greatest at the door, and thinnest near the bridge: the air by this kind of fire is restricted where it should have free access, and where it has access it should be shut out.

The Scoop Fire.—To maintain steam, to consume as much smoke as possible, to admit as little cold air as possible, and to work coal to the highest point of economy, the fire requires to be made and maintained through the day to a form resembling a scoop.

The thinnest part of the fire should be near the door, the sides well piled up, and a good thickness of fire against the brick arch. A fire of this form is built upon the principle that air requires plenty of room to enter the furnace and less facility for leaving it, so that there may be a proper admixture of the gases, that they may be fairly ignited and at the highest temperature possible *drawn* into the tubes.

Combustion in a furnace thus conducted is more perfect than in furnaces worked with pancake fires. The mass of incandescent fuel piled against the bridge is an effectual barrier against the air rushing into the flues comparatively cold, and it is as equally effectual in maintaining an equal temperature about the ring-seams. The air, on entering by the furnace door, which should be done near the bottom, as in Martin's plan, is raised in temperature and expands, by which

its volume is increased and its velocity is accelerated. To counteract this the fire is tapered, so that the cubical capacity of the furnace for air is gradually reduced from the door towards the bridge, and therefore the air is brought into intimate contact with the gases, and a proper admixture is insured. If the mixture has been imperfectly performed in the front portion of the furnace, a more complete combustion will take place near the bridge, in the neighbourhood of the thickest of the fire.

Mode of Firing.—The greatest saving is effected by side firing and half-end firing, always leaving one side perfectly bright. This is the best practical mode for accommodating the gases and for properly introducing the requisite quantity of air.

But that is not all; there are two conditions on which complete combustion is dependent—the proper proportion of combustible gases and air in mixture, and the maintenance of temperature. Suppose a furnace-door is opened with plenty of burning coal on the bars, the steam cannot be kept up. By putting on more coal, we are as badly off for steam. The explanation is that the gases of the coal and the oxygen of the atmosphere combine only at a certain temperature. By side firing, the temperature of the furnace is maintained more nearly to the required degree than when both sides are fired at once. Further, by side firing the intermittent expansion and contraction of the plates of the boiler is considerably reduced.

Intervals of Firing.—The intervals between firings depend upon the character of the coal, the strength of the draught, and the demand for steam. Some kinds of coal will not be hurried; if subjected to a sharp draught, they fall to slack. Such is anthracite.

The best way to procure good firing, free from smoke, economical, and to keep down the coal bills, is to employ intelligent firemen.

Numerous plans have been resorted to for the perfect combustion of smoke, and for making steam out of the minimum amount of coal, but the best constructed invention is annulled unless there is a thinking head between the coal heap and the furnace.

There is required something more than shovelling if the principles of combustion are to be followed. If they are observed, who suffers? Not the shovel-man. If a man in charge of a furnace is a total stranger to the principles affecting combustion, no ingenious mechanical arrangement, no scientific apparatus, can supply the deficiency.

It has been stated that mechanical appliances for firing have a tendency to beget lethargy and to convert the firemen into machines themselves; that there is no intellectual activity required, and that the vacuity in the mind is filled with trash. In support of this view, it is said that many excellent and ingenious smoke consumers have "gone under" because the men would not take to them. If they were asked to give a reason, they would spare no trouble in telling you "it didn't suit them." There may be some truth in this. Some men pride themselves upon possessing an opinion, so called, no matter how glaringly it may be opposed to facts.

Qualifications of a good Fireman.—A good fireman is guided in his duties by three considerations, namely, knowledge of the boiler, knowledge of the coal, and a knowledge of the principles of combustion. To set down any one general rule for providing an adequate

supply of steam would be impossible unless all boilers were alike, and coal were of the same quality. A man, to bring his knowledge of firing up to the highest point of proficiency, to give the best economical results, must not only understand how to put coal on, but he must know his boilers, that is to say, the capabilities of the furnace.

He must also be a good judge of coal when he sees it, and able to tell within reasonable limits what he can do with it. There are many kinds of coal. There is a bituminous coal; there is a slightly bituminous and a semi-bituminous coal; and there is anthracite coal. These are distinguished by their appearance, and they may be known at a glance by their colour, lustre, and cleavage. A bituminous coal, such as cannel, contains a deal of tarry matter and other ingredients, which are technically known as hydrocarbon. Such coal makes much smoke and more ash than other kinds of coal. It demands a special degree of skill to work it, and a large grate, over which to mix plenty of air with it. A slightly bituminous coal, such as Welsh or anthracitic coal, contains very little tarry matter and makes but little ash. Comparatively speaking, it is smokeless, although not literally so, but what smoke it emits is clean. Under the influence of heat, the coal assumes an appearance which reminds one of a head of cauliflower. Welsh coal contains a very small amount of hydrocarbons, and is therefore the best of steam coals. Semi-bituminous coal, such as Derbyshire coal, contains hydrocarbons to a considerable degree, but not to such an extent as to require more than ordinary attention.

Those who use steam power at a distance from the pit-mouth should use Welsh coal and semi-bituminous

coal in equal proportion, which should be mixed prior to being used.

With an entirely smokeless coal, combustion takes place with little or no flame, and the heat from the incandescent mass on the bars is rapidly absorbed by the water in the vicinity of the furnace.

When a mixture of coal is used, there is a development of gas and flame which the current of the draught induces to flash along the tubes and flues, where there is an abundance of heating surface ready to take up the heat. At any rate, a judicious mixture has a tendency to insure a more equal temperature of heat throughout the boiler. This is a cardinal point.

From the above remarks it may be inferred that there are four classes of coals, regulated by chemical composition, and that those which contain the most tarry matter, that is to say, having a large per-centage of constituent hydrocarbons, make the most smoke.

What is smoke?—When we see a beautifully clean lamp-globe soiled by a black cloud, we instantly turn down the wick a little. The cloud of black smoke, either issuing from a globe or a chimney, is the result of precisely the same causes. If the lamp is well supplied with oil and cotton, and there is abundance of flame and smoke, the smoke is caused by an insufficiency of air to effect perfect combustion of the combustible matter, oil.

It may be asked, why does the lowering of the lamp-wick slightly make all the difference between a black cloud and a white light? The answer is, the relative proportions of combustibles and air are then exactly adjusted.

The five following tables exhibit the physical results of the behaviour of several varieties of coal. The degree of attention required is not regulated in all cases by their smoky nature, but also by their tendency to produce clinker. This tendency can in all cases be modified by regulating the draught.

TABLE 1.—WELSH COAL.

Name of Coal.	Burns.	Smoke.	Attention required.	How to fire.	Draught required.
Aberdare	freely	little	ordinary	little & often	ordinary
Aberaman	do.	do.	do.	do.	quick
Anthracite	difficultly	none	careful	do.	quick
Mynydd Newydd ..	cakes	much	much	do.	ordinary
Nixon's Merthyr ..	diff.	little	careful	do.	quick
Brymbo	quickly	much	much	do.	moderate
Rock Vein	do.	do.	much	do.	do.
Ebbw Vale	freely	little	careful	do.	ordinary
Duffryn	do.	none	little	do.	do.
Plymouth Works ..	slowly	little	much	do.	quick
Neath Abbey......	freely	much	do.	do.	ordinary
Vivian-Mirfa......	cakes	do.	do.	do.	brisk
Abercairn	do.	mod.	do.	do.	do.
Bedwas	freely	little	careful	do.	ordinary
Resolven..........	do.	do.	do.	do.	do.
Graigola..........	do.	do.	do.	do.	do.
Machen Rock......	do.	do.	do.	do.	do.
Birch Grove	do.	do.	do.	do.	brisk
Cadoxtan	diff.	none	little	do.	ordinary
Pentrepoth........	do.	much	much	do.	brisk
Llangennech	slowly	little	do.	do.	do.
Cwm Nanty	freely	do.	little	do.	ordinary
Cwm Frood	do.	much	careful	do.	do.
Rock Vawr........	do.	little	little	do.	do.
Porth-Mawr	do.	much	careful	do.	do.
Pontypool	do.	do.	do.	do.	do.
Fiery Vein	do.	little	little	do.	do.
Gadby's Seam	slowly	none	do.	do.	strong
Coleshill	freely	much	much	do.	ordinary

TABLE 2.—DERBYSHIRE COAL.

Name of Coal.	Burns.	Smoke.	Attention required.	How to fire.	Draught required.
Butterly Co. Longly	freely	much	careful	little & often	ordinary
Butterly Co. Portland	freely	do.	do.	do.	brisk
Loscoe Soft	freely for a time	do.	constant	do.	ordinary
Loscoe Hard	freely for a time	do.	do.	do.	do.
Staveley	freely	do.	ordinary	do.	do.
Elsecar Fitzwilliam.	do.	do.	constant	do.	brisk
Elsecar Hoyland & Co. ..	do.	do.	do.	do.	do.

TABLE 3.—NEWCASTLE COAL.

Name of Coal.	Burns.	Smoke.	Attention required.	How to fire.	Draught required.
Willington........	cakes	much	constant	little & often	brisk
Tawfield..........	do.	do.	do.	do.	do.
Bowden Close	do.	do.	do.	do.	do.
Haswell Wallsend..	do.	do.	do.	do.	do.
Newcastle Hartley..	difficultly	do.	careful	do.	strong
Hedley ditto	freely	little	little	do.	ordinary
Buddle's West Hartley	do.	do.	do.	do.	do.
Carr's Hartley	do.	much	careful	do.	do.
Davison's West Hartley	do.	do.	do.	do.	do.
Derwentwater Hartley	rapid	do.	constant	do.	do.
Original Hartley ..	do.	do.	do.	do.	do.
Haswell Coal Company, Wallsend..	freely for a time.	do.	do.	do.	do.

TABLE 4.—SCOTCH COAL.

Name of Coal.	Burns.	Smoke.	Attention required.	How to fire.	Draught required.
Elgin Wallsend ..	freely	much	careful	little & often	ordinary
Wellwood	do.	do.	do.	do.	do.
Dalkeith Coronation	do.	little	ordinary	do.	do.
Kilmarnock Shevington	do.	much	careful	do.	do.
Fordel Splint......	do.	do.	do.	do.	do.
Grangemouth	do.	little	ordinary	do.	do.
Eglinton..........	rapid	much	careful	do.	do.
Dalkeith Jewel	freely	little	ordinary	do.	do.

TABLE 5.—LANCASHIRE COAL.

Name of Coal.	Burns.	Smoke.	Attention required.	How to fire.	Draught required.
Balcarres Arley....	freely	much	careful	little & often	ordinary
Blackley Hurst	do.	do.	do.	do.	do.
Johnston's and Worthington's ..	do.	do.	do.	do.	do.
Haydock Little Delf	do.	do.	do.	do.	do.
Ince Hall Pemberton 4-ft......	do.	do.	do.	do.	do.
Caldwell and Thompson's	do.	do.	do.	do.	do.
Wigan 4-ft.	rapidly	do.	constant	do.	do.
King	do.	do.	do.	do.	brisk
Cannel (Wigan) ..	freely	do.	careful	do.	ordinary
Blackbrook Rushy Park	do.	little	ordinary	do.	do.
Balcarres (Lindsay)	freely for a time	much	careful	do.	quick
Balcarres Haigh Yard	steadily	do.	do.	do.	ordinary
Caldwell and Tompson Rushy Park	freely	do.	do.	do.	do.
Haydock Higher Florida	freely for a time	do.	do.	do.	do.
Haydock Florida Vein	do.	do.	do.	do.	do.
Haydock Rushy Park	do.	do.	do.	do.	do.
Balcarres 5-ft.	freely	do.	do.	do.	do.

The varieties of coal are very numerous, and therefore it cannot be expected that all coals can be treated alike. The differences of composition may be but slight, and still a slight difference may suffice to give a coal a favourable character in the eyes of the fireman, who may prize it because it requires the least attention.

The popular opinion is that Welsh coal is the best for placing at the engine-house door for a fireman to run at. Why? Because the burning of the carbon is not as difficult a matter as knowing how to manage the hydrogen. To this difficulty much of the complication attending the use of smoky coal may be attributed. We will now endeavour to point out how the hydrogen should be managed; but before doing so it is well to explain that Welsh coals contain the least proportion of hydrogen, and that the Scotch coals contain the most hydrogen. The former is called smokeless, which is scarcely the case; and the latter are called smoky in a superlative degree. From this it is readily inferred that hydrogen in excess produces smoke. Dealing first of all with anthracite, we observe from the table of Welsh coals that it is difficult to burn, and requires careful attention, with a quick draught. This coal is very dense, or stone-like; and, if sufficient air can be brought in contact with it, it gives out an intense heat, without flame and without smoke. Now, being dense, the atoms lie close together; they are packed, so to speak, into small compass; and being so close together there are more of them in a cubic foot than there are in, say, a cubic foot of Aberdare coal. It must be observed that each atom of carbon requires a specific quantity of air for its perfect combustion, and therefore anthracite requires a quick

draught, which means plenty of air. This coal is not much used for raising steam in this country.

The Aberdare coal, which is extensively used on railways, is almost smokeless, and it is not so dense as anthracite, and therefore it burns more freely. There are fewer atoms per cubic foot of coal, and therefore less air is required per cubic foot. This coal requires less attention. The air can cleave its way into it, which causes it to swell and open out. The air can get into contact with it, supplying to each atom its equivalent of oxygen. There being very little hydrogen present to "pick up" the air, perfect combustion is nearly attained. At all events, a strong heat is given out as the result of the proper admixture of air and carbon. This coal is usually said to be smokeless, but most of the best qualities emit a light vapoury smoke. It does not bear rough usage, and it crumbles rapidly after long exposure to the atmosphere. This circumstance, together with the loss, in some descriptions, by falling through the fire-bars in consequence of its falling to pieces by the heat, renders it prudent to mix with Aberdare coal a harder kind of coal, such as Longly or Derbyshire.

Let us now examine another Welsh coal which smokes, namely, Mynydd Newydd. This coal not only smokes, but it cakes, and this is caused by its containing more hydrogen than Aberdare, more constituent oxygen, and more sulphur. These elements in excess are sufficient to produce marked effects on its physical character. Let us bear in mind that the hydrogen is the chief element which causes smoke, and that when in the furnace we have no control over it, but that we have control over the air, and we can also have at our

command a quantity of carbon in an incandescent state on the bars, from which all the hydrogen has been expelled, and has been consumed, or has escaped up the chimney. Let us also remember that every atom in the furnace requires so much air, and that the air-spaces between the fire-bars, and the holes or slots in the fire-door, can only admit a certain quantity. If, then, to make this plain, we have, for instance, 12 atoms of carbon and 12 atoms of hydrogen in the furnace, and we only admit sufficient air for 20 of them, the hydrogen will seize 12 and the carbon will be left with 8, and smoke will be the result as the hydrogen becomes consumed. When there are 12 of carbon and 8 of hydrogen the air is sufficient, and combustion is stated to be perfect. The coals are then consumed, but when the coals cake it is a sure sign that the air has only been sufficient to "melt" them together, and not sufficient to consume them; and no one will deny for a moment that air is capable of consuming all kinds of coal, and therefore a caking coal can be burned as well as melted. To do so, there must be a good body of clear fuel on the grate, and there must be a limited quantity of fuel added at a time, so as not to choke the draught. In dealing with caking coal there must be a brisk draught to mix with the pasty materials, to reduce them to the consistency of dry coal, then the coal can be consumed with good results. It may be mentioned here that, when caking coal is supplied to a locomotive, the usual remedy applied by the driver is to keep it "on the dance," which simply means working with a brisk draught. In this case, as in all others, the depth of the fire varies with the demand for steam. It may be stated that, when coal

cakes, it is piled on too deep, and there is a deficiency of air.

We will now pass on to another class of coal—Derbyshire—which differs from many others in its excess of constituent oxygen, with a percentage of hydrogen very slightly greater than that contained in Welsh coals. These differences have a great influence on economical results. This coal is also inferior in carbon compared with Welsh and Newcastle, but is superior to Lancashire. The element of hydrogen in Derbyshire coal loses a portion of its value owing to the fuel containing an excess of oxygen, and the more oxygen a fuel contains the less power it has to make steam.

When oxygen is present as a constituent of coal, it is saturated with hydrogen and is converted into aqueous vapour, and rises in this form from the fuel-bed without having passed through the heat-giving process of chemical combination in the gaseous form. Some enginemen are in the habit of watering these coals, and they find it improves them. To simply wet the surface of a heap of large coals would produce no perceptible effect, as they are too hard to absorb water; but when they are broken up a vastly increased surface is exposed, and certainly more water is utilised. But the gain lies more in the quantity of water picked up at the bottom of the heap, when firing, by the shovel.

A smoky furnace or fire-box can be cured for a very short time by sprinkling water into it with a brush or scooping it in with a shovel. This effect is no doubt well known, and we may at once explain the cause. Water consists of one volume of oxygen and two volumes of hydrogen; or one part by weight of hydrogen and eight parts of oxygen. One pound of hydrogen

is worth five times a pound of carbon. If, then, we apply water to an open-burning coal, the water is decomposed; or, what is the same, the hydrogen leaves the oxygen and aids the evaporative power of the fuel. Many enginemen will remember that they used to water coke to make it burn better or last longer; now, coke is nearly all carbon, and it generates great heat. Hydrogen is a gas, and for equal weights, as already mentioned, it gives more heat than carbon. Much of the apparent complication of the process of combustion vanishes when it is borne in mind that carbon and hydrogen burn and oxygen does not.

From what has been stated, the more hydrogenous the fuel the greater is its heating power, and in dealing with Derbyshire coal it should be broken into pieces and well watered, as the water is of more value than an equal weight of either coal or coke.

It is impossible to give a standard depth of firing for any coal, or even for the same coal; for when Welsh coal is small it restricts the passage for air, especially when the draught is moderate. As the chemical action between fuel and oxygen can only take place when the two are in intimate contact, the rapidity and completeness of combustion and intensity of heat will be increased by increasing the number of points of contact or by reducing the size of the pieces of coal. This brings us face to face with the fact that coal should be used in very small pieces, even as dust, or, better still, as gas, in order to obtain the maximum value. Now this is impossible in practice in ordinary furnaces, and the next best thing to do is what is possible, namely, to reduce the coal to a reasonably small size, and small depth of fire, in order to obtain intimate contact. Each

atom of coal only takes up its equivalent quantity of air to consume it, and no more, and therefore the depth of the fire must be regulated by the rate of admission of air, and this will depend upon the quantity of coal as well as the size of it, upon the ratio of grate-area to effective heating surface; and also upon the demand for steam. Most of the coals in the Newcastle district yield a large percentage of hydrogen or gas, and they need an excess of air for combustion. As this gas is on the top of the fire, it follows that the air for it must be supplied above, from the doorway. By careful firing, and by admitting a sufficient quantity of fresh air direct to the gas, this kind of coal can be burnt without smoke. When coals melt together it is proved that the draught through the bars requires to be increased or the thickness of the fire to be reduced. The reduction of caking is owing to the rapidity with which the coal is burned. Intensity of combustion has the effect of maintaining an igniting temperature, whereas if the same amount of fuel is burned slowly, its heat may not be high enough to ignite the gases as they are produced, and hence the coal runs together. The Scotch coals contain more hydrogen than the Newcastle coals, and they contain a very large percentage of oxygen, like the Derbyshire coal. This raises the hydrogen from the fuel-bed and prevents caking, and therefore these coals are very smoky indeed. On the control of the supply of air depends all that human skill can do in effecting perfect combustion and economy. Unless the supply of fuel and the quantity in the bars is regulated, it is impossible to get sufficient air into the furnace to complete combustion.

The Lancashire coals burn very freely, with much

smoke, as they come next in order for hydrogen compared with Scotch coal. These coals contain the least carbon of any, and they also contain a large amount of oxygen. From the fact of the Lancashire coals being poor in carbon, the fire requires to be made as deep as possible; and, as they contain plenty of hydrogen, the air above the coals will have to be supplied in sufficient quantities to supply the gas with oxygen. The reason why plenty of coals must be piled upon the bars is that before the gas is expelled from the fresh coals they must be heated to a temperature about 1,200 degrees, and this heat will be abstracted from the glowing carbon. To consume the requisite quantity of carbon from poor coal it is necessary to have a larger bed of coals on the bars compared with a coal containing plenty of carbon, such as Welsh, in order to obtain sufficient heat to raise the gas to the required temperature without checking the steam. Suppose that 100 pounds of coal, at a temperature of 50 degrees, be put on a fire, it would absorb 23,000 units of heat before the gas is expelled, and therefore the more heat we have for raising the gas the better for the furnace and for the steam. If we can spare the heat without affecting the steam it is only reasonable to suppose we have plenty of it, and that means plenty of carbon. In dealing with coal resort must be had to a kind of private experiment, and an engineer should avail himself of this privilege of trying to burn coals with the utmost economy by altering the draught and the depth of the fire in order to suit different classes of coal. To burn slack, which is the most difficult of all fuels to burn without smoke, the only means is to keep up an almost continuous fire of small charges. With all coals,

no harm can arise by making up a fire at the commencement and submitting it to a moderate draught, which is coking the coal, in order to get a firm foundation of coke, upon which a moderate amount of coal at each firing can be thrown. To avoid clinker is, in many instances, impossible, owing to the demand for steam, as a rapid draught is associated with these fire-eaters. If a fire is made up with clinkery coal in a house, it does not produce clinker; or, if it is allowed to burn in a furnace with a very moderate draught, clinker is not produced. Even with Aberdare coal, on the contrary, with a strong draught, clinker is considerable. In conclusion, Welsh coal requires very little air above the fuel; and all the other coals require plenty of air admitted at the doorway. Welsh and Derbyshire coal, being poor in hydrogen, are improved by wetting, and all the others, having an excess of hydrogen, do not require wetting to improve their heating power.

Gas coke, now much used in towns, is coal somewhat purified; but so far as the shape of the fire is concerned it can be treated as coal, and it is improved by wetting. It is easily managed and is comparatively smokeless.

In concluding this chapter it will be well to mention that a lamentable waste of good fuel is constantly going on for the want of a very simple arrangement in the ash-pit. Owing to defective fire-bars, some too short at first and others burned short, with wide gaps between them, a considerable quantity of unburned coal drops through them into the ash-pit and is wheeled away with the ashes or dust. To avoid this waste some employers provide the fireman with a screen, and in process of time a tolerably large heap of savings is the

result. This process of screening diverts the fireman's attention from his duties, and now and again he allows the steam to go down. Now, instead of this mode of effecting a saving, it would be better to place another grate, or it will be better understood if we say at once—Why not put a screen in the ash-pit with a dead plate at the back, from which the fireman can shovel the unburned coal and put it into the furnace at once? This, then, would leave nothing but the ashes to clear away and save time. The screen could be made so as to be drawn in and out of the ash-pit, and placed sufficiently low, so as not to impede the draught. Then, again, we do not burn so much clinker over again as is possible and beneficial both for the draught and for the protection of the fire-bars. The clinkers should be mixed with the coals and shovelled on with them, and the result will be a better and hotter fire with them than can be obtained without them. They keep the coals apart and make openings for the air to enter the fire. They are especially valuable with small coals; for they will not form clinker again, and they materially assist in preventing other clinkers from forming.

CHAPTER XIII.

MANAGEMENT OF THE FEED-WATER AND OF BOILER FEEDERS.

THE maintenance of steam depends to a considerable extent upon the manner in which the boiler is fed with water. The aim should be, as far as possible, to regulate the supply to the demand—just sufficient to keep the water at one level in the gauge-glass. By doing so, an even temperature may be maintained within the boiler, which may be the means of prolonging its life, as an irregular temperature shortens it. There are various opinions as to the benefits derived by heating the feed-water by the exhaust steam; but opinions are unanimous that the feed-water should be heated before it enters into the boiler. At the best of times feed-water can only be heated to 212°, and even at that temperature there is a considerable difference between the temperature of the feed-water and that of the boiler.

The objections advanced against heating feed-water by injecting the exhaust-steam into it, are founded upon the fact of grease having been found upon the surface of a burnt boiler-plate. To the deposition of such grease, in conjunction with carbonate of lime, the burning of boilers is attributed. There can be no

question that a thin film of grease combining with carbonate of lime, a floury deposit, prevents the contact of water with the hot plate, just as surely as grease prevents a revolving axle from touching the journal or brass. Besides, the presence of grease increases the tendency of many boilers to prime, and hinders the circulation of the water, by forming, with mud and other matters, an insoluble soap, and thus causes no end of trouble. It searches out every particle of carbonate of lime, priming is set going, and out goes the cylinder end before the engineman is aware of it. The danger of using grease need not be dwelt upon, but the danger lies in the abuse of grease. When used in such infinitesimal quantities as are to be found in the feed-water when heated by the injection of a portion of the exhaust steam, it sometimes only has the effect of detaching scale from the plates.

There is an objection to heating the feed-water, either by injection or by passing it through a coil of pipes in water, in the precipitation of lime salts in the feed-pipes, which become choked. The pump in consequence becomes disabled. The feed-water, containing bicarbonate of lime in solution when cold, precipitates when heated the greater portion of the lime salts. The lime is left behind, or is left spread over the interior surface of the supply pipes between the cistern and the boiler. We must be prepared to attack and remove the lime before any disadvantage or inconvenience is suffered.

In practice, there are almost as many points for introducing the feed as there are boilers. In Cornish and Lancashire boilers, the feed is delivered very frequently near the bottom of the boiler, which is

the coolest part of the boiler. It was for a long time maintained that such was the proper place for the admission of the feed, to obtain the maximum evaporative efficiency. It was this consideration by which the earlier locomotive builders were led to introduce the feed by the side of the fire-box, even when cold; but, when the feed-water is not heated, such practice would never be tolerated in these enlightened days. Many boilers are fed at a level just below the fire-line, and the water, instead of being concentrated at a single point, is received from the feed-pipe by a perforated pipe or trough inside the boiler, by which it is distributed in the best manner so as to avoid extremes and to conduce to steady steaming. When the feed-water is naturally bad, containing impurities of a mechanical or a chemical nature, the influence of the impurities may, by continual watching, be detected in the boiler, steam-pipe, and cylinder. Should the water prove refractory in the boiler, and have a deteriorating action, the only remedy is to dilute it with the condensed water from the engine as much as possible, and by means of the scum-cock to clear the surface of the water in the boiler several times a day.

Now, as regards the saving of fuel by heating the feed-water,* if we take a boiler working to a pressure of 40 lbs. per square inch above the atmosphere, with feed-water at 60°—the normal temperature—the total heat absorbed in the formation of steam of 25 lbs. effective pressure from cold water would be $(1201{\cdot}0° - 60°) = 1141{\cdot}0°$. But, if the feed-water be heated to and supplied at 212°, the heat absorbed would amount

* A Treatise on Steam Boilers, by Robert Wilson. Fifth Edition, 1879. Crosby Lockwood & Co.

only to $(1201° - 212) = 989{\cdot}0°$, which shows a gain of $152°$, or $12\frac{1}{2}$ per cent.

Although a large measure of heat is economised and returned to a boiler in the course of a day by heating the feed-water, it must not be considered to be the sole element of good thereby effected. There are others, such as a diminution of intermittent expansion and contraction, purification of water, and constancy in steaming.

Feeders.—The necessity of great attention being paid to the perfection in principle, manufacture, and action of the pump for boiler feeding is obvious. The sinking of the water below its proper level in the boiler has not only caused many explosions, but it has also produced a considerable amount of inconvenience in a factory by causing the fires to be drawn, through a defective pump. It is not an uncommon occurrence for a lot of men who are working machines to be thrown idle for an hour because the engineman could not get any water into the boiler. In modern times, with so many feeders, such an accident should not happen. But then it does happen, and nine times out of ten it happens with the old apparatus—a pump. We may notice some of its faults.

The plunger, or piston, the valves, and the barrel may be faulty to begin with. The plunger may have been badly turned, and may not be truly cylindrical; the stuffing-boxes too large, they may be badly packed, or the pump-barrel may have been carelessly and unequally bored. The piston-pump is sometimes badly leathered, allowing air to enter, which destroys its efficiency.

The valves may be faulty in consequence of not

having been made of hard metal; they may be too small for passing hot water, and may have too much lift; they may be liable to wedge themselves and stick fast; they may have been formed with too much taper; the surface of contact may be too broad or too narrow; the valves may not be provided with proper means of access for repair or removal. These defects require to be constantly watched. There are a few other occasional deficiencies. Sometimes the suction-pipe is so placed that it may fail to act when the water is low in the well, and half a day may be lost in examining valves, &c. By the time these have been taken out and cleaned, and the obnoxious morsel of dirt found in the pump, the water in the well has risen, and when the fires are relighted and the engine set to work, the necessary quantity of water has been collected.

Again: when the water is known to be full of foreign matter—as straw, chips, sand, sawdust—it often happens that the engine attendant does not take any precaution to prevent its entering the pump with the water by the intervention of a strainer. In districts where the water requires to be strained, the strainer should not be fixed close to the suction-pipe, as this would interfere with its action, but it should be placed at a distance in a convenient position to form a division in the cistern or reservoir from which the pump is supplied, so that the impurities may be easily collected as required, and removed from the water.

The division may be made of fine wire, and so arranged as to divide the water into two unequal parts, into the smaller of which the water supply is delivered, and from the larger of which the pump is

supplied. The cistern must be covered in to keep the water free from objects that might be thrown into it.

The most ancient pump with which we are acquainted is that of *Ctesibus*. It was a force-pump which was used before the nature of a vacuum was understood, and therefore was in existence before the suction-pump.

A force-pump acts by pressure; a suction-pump by exhaustion.

In the ancient force-pump the water was brought into the body of the pump by gravitation, and it was forced out by a piston-plunger to any suitable elevation. The only valve was a stop or foot-valve to prevent the water, on the descent of the piston, from returning to the source of the supply. The water, therefore, found an exit in some other direction. The quantity of water obtained at each stroke would be equal to a column having the diameter of the piston and length of its stroke. This was a very simple pump; but when the water was required to be lifted above the pump, say through a vertical pipe, it is clear that on the piston making the out-door stroke, water would follow it and occupy the vacant space in the barrel more or less. If sufficient water followed the piston to completely fill the space left by it, then no useful work could have been performed, no water delivered. If the space in the barrel was half filled by returning water, then a useful effect equal to half the whole work done would have been secured, so that for a long time the lift of the water above the pump could have been only so far attained as the cubical capacity of the delivery-pipe was less than the cubical capacity of the barrel of the pump. Following this imperfect

condition of things, new wants required new improvements, and the next thing was the insertion of a head-valve, above the pump, in the delivery-pipe, so that the water was prevented from returning on the piston. The valve was made to open from the pump, and with a foot-valve and a head-valve, the arrangement was complete as for a force-pump. At this early period atmospheric pressure was not thought of for forcing water into a vacuum.

When the pump was put to work, water very soon began to flow, and the pump was said to lift the water, though why it should be able to do such a thing no one could explain. When the water is below the pump, the air is pumped off the top of the water, and is forced like water into the delivery-pipe; then the water rises into the pump. We will examine into the cause of the water rising in this manner, as hundreds of people have still a belief that the pump lifts it. The ancients could not explain it otherwise than by declaring that the cause was that "nature abhorred a vacuum."

For the real explanation we are indebted to Galileo and his pupil Torricelli.

The former philosopher taught that air had weight; the latter showed, by incontrovertible experiment, that the rise of fluids in pumps was owing to the pressure which his master was expounding to the brother philosophers of his day. These truths became the chief scientific questions of the hour, and they are at this day of great practical interest in the art of engineering.

Torricelli constructed a barometer, and he demonstrated that the pressure of the air on the surface of the water would raise the water from the well to the

pump-valve, provided that the distance did not exceed 34 feet, and that the air was all pumped out of the suction-pipe. The weight of the atmosphere on the ground is due to the superincumbent mass of air above, which is estimated by some to be not less than fifty miles high. This mass weighs 14·7 lbs., or nearly 15 lbs. per square inch of horizontal surface at the level of the sea, and the air, in virtue of its elasticity, exerts the same pressure in all directions on bodies which are exposed to it. Having made this explanation, we may now proceed to consider the action of the *suction*-pump, or the pump which is commonly stated to lift water.

A common back-door pump is one of this class—suction—and as every one is familiar with its effects, we may safely select it to assist us in our endeavours to inform young enginemen why it is called a lift-pump.

The common suction-pipe is fitted with what is called a bucket, being, in fact, a piston with a valve fitted to it opening from the water, which may be 20 feet below it. Below this valve there is another valve, opening from the water like the bucket-valve. When the pump-handle is lifted high, the bucket is lowered so that it almost then touches the lower valve, and when the handle is lowered, the bucket is lifted and it is placed at some distance from the lower valve, sometimes not more than six inches. But, as already stated, the water may be 20 feet lower, or more. The limit with a good pump is 30 feet. When the pump is not in action it is full of air in the interior of the barrel, and down the suction-pipe. There is air also on the surface of the water in the well. The pressure of the air within and that of the air without the pump

balance each other. Now, suppose we raise the pump-handle and bring the valves together, and then commence to pump. Upon elevating or raising the bucket, the air above it keeps the valve down, because it opens only from the inside; and, therefore, when the stroke is completed, the space between the valves is empty, being a vacuum, and it would remain so were it not that the air underneath the bottom valve gently insinuates itself past the valve and takes possession of the vacant space. As soon as the bucket is lowered, the air immediately under it is compressed. The bottom valve is thus closed, and the bucket-valve is opened, when the air escapes through the spout. Another up-stroke is made, in consequence of which the upper valve is closed, and another vacancy is formed. Air again enters this place, and it is pumped out as before.

It follows, then, that at every stroke the air within the pump is rarefied and its elasticity is diminished, and its presence is gradually got rid of inside the pump from the surface of the water in the suction-pipe to the underside of the bucket-valve. Thus far the pump has acted simply as an air-pump.

Now, having exhausted or sucked all the air out, there is, as between the interior and the exterior of the pump, unbalanced atmospheric pressure, and by the preponderating pressure of the air in the well outside the pump, the water is forced up the suction-pipe and through the bottom valve into the body of the pump, occupying the space between the two valves. The pump is then said to be charged. When the water is pressed by the lowering of the bucket there are two effects—one is to close the bottom valve, the other is

to open the top one, through which the water passes as the bucket is lowered; and when the two valves are brought close together, all the water is obviously now above the bucket-valve. The instant that we attempt to lift the bucket, the weight of the water closes its valve; and, therefore, by raising the bucket the water is lifted to the spout, through which it is discharged. Thus the pump is said to be a lift-pump. As the bucket is lifted, with its weight of water above, water is at the same time entering into the pump under the bucket to occupy the vacant space formed by it in its ascent.

This pump, the common suction-pump, operates by the formation of a vacuum within the working barrel; and it is incapable of raising water from a level more than 34 feet deep. But water may be delivered at great distances by employing valves and air-vessels, as in the case of waterworks, so that a pump may be so constructed as to draw the water by *suction*, and *force* it to any required height. Such is the principle of the pump, worked either by manual or mechanical power. There are bucket-pumps, piston-pumps, and plunger-pumps.

A *bucket-pump* is a single-acting pump: the bucket being a piston with a valve fitted to it in the centre which closes on the up-stroke and opens on the down-stroke, lifting a quantity of water equal to only the capacity of the pump in one revolution of the engine. It is fitted with foot and head valves. Such a pump we have just considered.

The *piston-pump* is either single-acting or double-acting. It is fitted with suction-valves and delivery-valves in juxtaposition with the working barrel.

The *plunger air-pump* is a double-acting pump, arranged like the bucket air-pump, except that there are no head-valves, and that the bucket-rod is fitted with a large plunger. The effect of this is that, whereas the ordinary bucket air-pump discharges only with the up-stroke, the plunger air-pump, owing to the displacement caused by the bulk of the plunger, discharges on the down-stroke as well.

Injector.—Since the injector was invented by Giffard, and brought into practice, it has generally done its work satisfactorily, and at a small cost for feeding the boiler.

It was a great novelty when first introduced, and it very soon became a favourite with railway enginemen; and the cause is not far to seek. It could be used either when the engine was disabled, or when the train was put into a siding. It was a friend in need under trying circumstances, such as are common upon a railway, when a pump could not afford the same help. I refer to train-engines that are delayed upon the main line or on branch lines by an accident in front. It used to be a very common practice under such circumstances to draw the fire in order to save the boiler. To do so in these days would be to degenerate to the old style. At a small expense, an injector can be provided and attached to every engine, and in every engine-house.

Probably no invention was ever placed in the hands of enginemen that they knew so little about, and which they were yet able to work efficiently. Not one engineman in five hundred can explain the action by which the instrument delivers water into the same boiler as that from which it is supplied with steam.

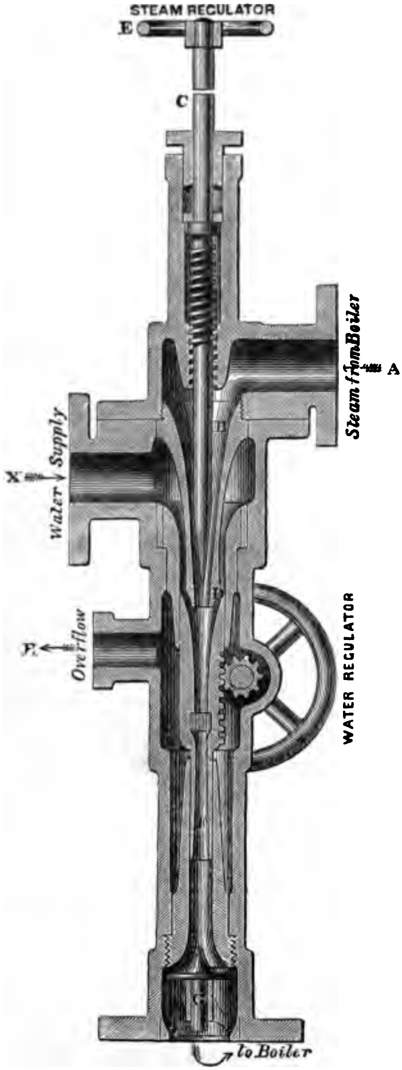


Fig. 19.—Giffard's Injector.

It has formed the chief topic of warm discussions over many a flowing tankard; it has led to blows; it has divided the best of mates, for it is a "nut" that few, very few, in the engine-house, have the fortune to be able to crack.

Steam is admitted into the injector through a cock on the boiler, to obtain steam free from water. When the cock is open, steam can enter the injector through A, and occupy B surrounding the spindle C. The spindle is finished conically at its lower end, and forms a valve which may be closed steam-tight at D, controlling the egress of the steam into the lower por-

tion of the injector. When the wheel E, on the end of the spindle C, is moved to raise the spindle, steam rushes through D, past the mouth of the inlet-pipe X leading from the water-supply. The current of steam by the suctional action draws the air out of the pipe leading to the water, and relieving it of atmospheric-pressure, a vacuum is formed in the pipe between the injector and the water, by virtue of which it ascends and enters the injector.

The action of the injector is entirely due to the *concentration* of the steam issuing from a cone, A, Fig. 20, which must be taken as representing the *power* of the instrument. Here the steam is condensed, and is concentrated by means of the water flowing in at the combining cone B. The united streams of water and steam are passed into the receiving cone D, where the *resistance* to the entry of the water into the boiler is experienced. The sectional areas of the cones differ, as a matter of course, and the areas of A and D, at their smallest diameters, are about as 2·0106 is to 0·7854.

The injector takes advantage of the superior velocity with which steam issues from a boiler as compared with water, and may be regarded as an instrument for producing a combined jet of steam and water, flowing through a nozzle at a higher velocity than that at which a corresponding stream of water would issue from the same boiler that supplies the steam.

When the water comes within the scope of the current of steam, it is carried along by the concentrated steam acting upon it. The water, which is incompressible, is projected forward into the delivery-pipe, and thence into the boiler by the impulsive force of the steam, the velocity of the steam being due to its elastic

pressure. The expansive force of gunpowder is confined by the shot to the powder-chamber, where the force is concentrated that ultimately sends the ball hissing through the air. So with the action of injectors, the force is concentrated by the water at the cone, and instead of there being one effect as with a charge of powder for one shot, the injector, whilst steam is on, is *always* charged, and there is a *continuous* discharge of water.

The reason why an injector will not work with feed water of a greater temperature than from 130° to 150° is that it requires so large a quantity of water to condense and concentrate the current of steam from the cone A, that the speed of the water cannot be sufficiently accelerated by the force of the steam to overcome the virtual speed of a corresponding stream of water issuing from the boiler.

The ratio of the quantity of water entering the boiler is to that of the steam used, as about 18 to 1; that is to say, that for one pound of steam issuing from the boiler, eighteen pounds of water are forced into the boiler. The temperature of the water is raised nearly 100° Fahr. during its passage into the boiler when the pressure is about 70 lbs. per square inch.

From this explanation an engineman should be enabled to form at any time an opinion respecting an injector that is defective in its working.

We will assume that, after an injector has been at work all right for a short time, it throws off—stops working.

There are three causes by which a stoppage is produced:—First, the injector will go off when the water exceeds a certain heat; but it may be argued that as the injector took the water at first, why not continue

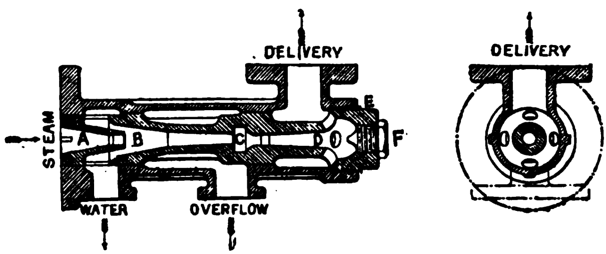
doing so? Because the injector itself may have been cool when first set on, and thus have assisted to a greater or less extent to cool the steam until it became heated. Secondly, the water in the tank may not have had the same temperature throughout, and as the hotter portion entered the injector, it failed to cool the steam and concentrate it. Thirdly, the injector will throw off when the volume of issuing steam from the boiler is insufficient to give the required speed to the water, so as to overcome the resisting pressure of the water and steam within the boiler. Here again it may be said: But the steam worked the injector at first. Yes; but the water which has been put into the boiler was comparatively cold, and this has reduced the temperature of the steam, and consequently its velocity into the cone A, whilst the volume of water remaining the same as when the injector was first put on, the steam is condensed *entirely*, and there is not sufficient speed given to the water.

We never see an invention, however good, but it is capable of being improved upon. This is the rule of the road which reaches to the goal of perfection.

Giffard's injector is very sensitive, and its mechanism is very much boxed-up, and when constantly put "on" and "off" it wastes much water through the overflow-pipe at each operation.

The advantages claimed for the Sheward and Gresham injector, Figs. 20, over the Giffard injector are, first and foremost, that it will take hot-water, whose temperature does not exceed 150° Fahr.: this is attended, as every engineman knows, with many advantages. There are occasions when the engine has been stopped, on which the boiler is overcharged with

steam, and when it blows off at the safety-valves; not only making an unbearable row, but wasting steam. If this disagreeable din and waste can be avoided by blowing back surplus steam into the tank, without annulling the power of an injector, it must, to say the least, be of great benefit. Such is the Gresham injector, of which the next recommendation is, secondly, that it readily adapts itself, without adjustment, to the varying pressure of steam under which the injector has to work. The advantage of this is like that of a pump which can be regulated so as just to maintain the water



Figs. 20.—Sheward and Gresham Injector.

in the boiler at the best working level; but, very unlike the pump, the water through the injector enters the boiler in a continuous stream, in place of by such intermittent action as is common to pumps. In fact, the injector, compared with a pump, may be considered as a continuous ram with a continuous piston. Thirdly, the advantage of being able to withdraw the working-parts of injectors may have struck many enginemen who have had experience of them. In the injector now under notice, the *whole* of the internal parts can be withdrawn from the external case without breaking any pipe-joints, by means of the nut E, and the interior,

which sometimes gets choked or furred up, can be cleaned and the instrument returned to the case with the steam up.

Some inquisitive spirits will want to know *why* this injector takes *hot* water. The explanation is that it is due to the good proportions of the various cones, and to the fact of their being fixed as much below the level of the supply-water as possible.

Instructions for working the Gresham Injector.—1st. Open the water-supply *slightly* by the cock on water-supply pipe, when, with a non-lifting injector, the water will enter it.

2nd. Open the cock on steam-supply pipe slightly until water issues freely from the overflow-pipe; then open the cock full. If water continues to issue from the overflow-pipe, regulate the water supply until this overflow ceases.

The quantity of feed-water supplied to the boiler through the injector may be increased or decreased at pleasure by opening or closing the regulation-cocks.

The Hancock Inspirator.—This instrument, an American invention, constitutes a still further advance upon the Giffard injector. It is a double apparatus, Fig. 21, one-half of which is a lifter, consisting of a lifting jet and a lifting nozzle; and the other half a forcer, consisting of a forcing jet and a forcing nozzle or injector; the lifter drawing the water and delivering it to the forcer, which delivers it to the boiler. Although both the lifting and the force-nozzles are fixed, their proportion, one to the other, is such that the inspirator does not require any adjustment for changes in steam-pressure or in water-supply, the waste-valve being kept closed while the instrument is in operation,

except at the time of starting. By means of the inspirator, water can be lifted 25 feet, and delivered into

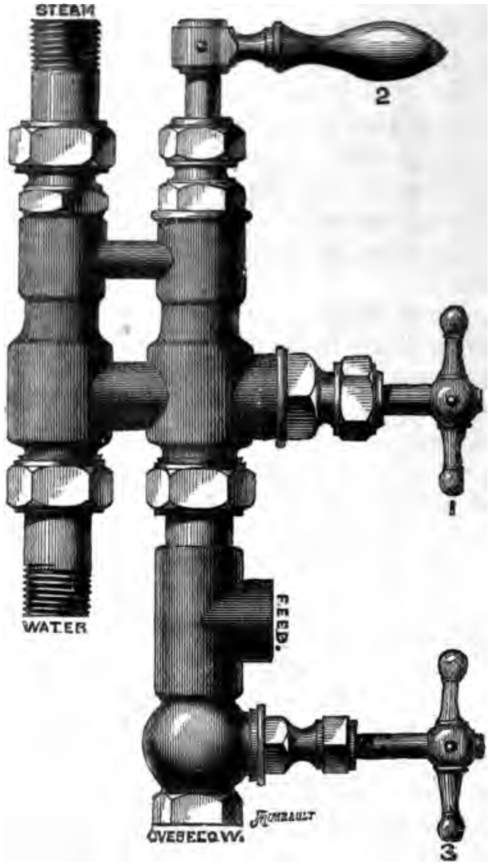


Fig. 21.—Hancock Inspirator. Stationary Boilers.

a tank or a boiler, as required, with a steam-pressure of 30 lbs. per square inch. The temperature of the

water may be as high as from 90° to 100° Fahr. for a lift of 25 feet; or it may be as high as 125° Fahr.

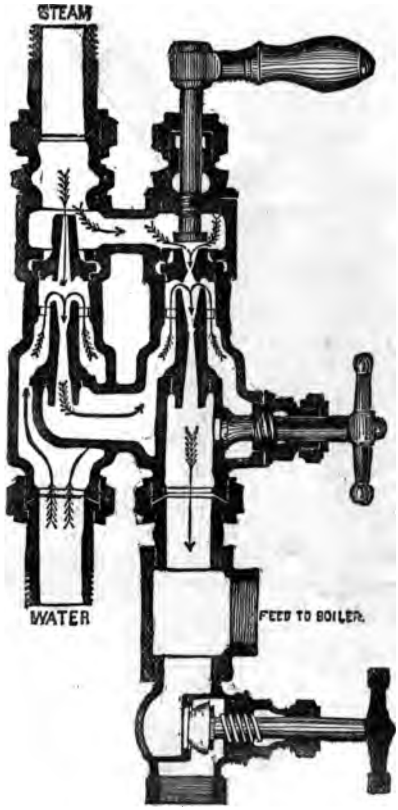


Fig. 22.—Hancock Inspirator. Vertical Section.

for a lift of 3 or 4 feet. The inspirator for stationary boilers is shown in section, Fig. 22. By means of the uppermost valve, the admission of steam to the

forcing jet is controlled; by the middle valve is regulated the flow of the water delivered by the lifting jet

Fig. 23.—Hancock Inspirator for Locomotives.

into the forcing tube; by the lowermost valve the overflow is opened and closed.

The locomotive inspirator, shown in Fig. 23,

deserves a word of notice. It is the same in principle as that of the stationary inspirator; but the arrangement is such, that all the operations of starting and stopping can be performed by the movement of a single lever, and the instrument is self-contained. By a slight movement of the starting lever, steam is admitted to the lifting jet. When water issues from the overflow, by a further movement of the starting lever one of the valves is closed—thus turning the supply water through the force-nozzle—steam is admitted to the forcing-jet, and the waste-valve is closed, thus starting the instrument.

An elaborate series of trials of the Hancock inspirator was conducted at Boston, U.S., by Mr. R. H. Buel. According to a table of some of the results of these trials with No. 30 instrument, for stationary boilers, in which the smallest diameter of the force-nozzle was 0.30 inch, or nearly $\frac{5}{16}$ inch, when the lift was from 2 to 3 feet, and the temperature of the water supplied was 70° Fahr., whilst the pressure of steam supplied to the inspirator, as well as the pressure against which water was delivered, varied from 15 lbs. to 150 lbs. per square inch, the maximum rate of delivery varied from 100 cubic feet to 144½ cubic feet of water per hour; and the minimum rate of delivery, when the steam-valve was wide open, and the supply was throttled, was from 60½ cubic feet to 78 cubic feet, with steam of 140 lbs. pressure. The temperature of the water at maximum delivery varied from 103° to 191° Fahr.; at minimum delivery, when the steam-valve was opened wide, and the supply throttled, the temperature varied from 184° to 230° Fahr., under pressures of from 40 lbs. to 150 lbs. per square inch; and, at minimum

delivery, when the steam-valve was throttled, and the supply-valve was opened wide, the temperature varied from 134° to 168° Fahr., under pressures varying from 80 lbs. to 150 lbs. per square inch. The vacuum in the supply-pipe varied from 4 inches to 23½ inches of mercury, between the extreme pressures of from 15 lbs. to 150 lbs. The lowest pressure of steam with which the inspirator delivered water against these extreme pressures, varied from 11 lbs. to 90 lbs. per square inch.

From the results of another series of experiments, it appears that with a lift of 2 feet, for pressures of from 15 lbs. to 150 lbs., the highest admissible temperature of supply water varied from 130° to 144° Fahr., and the temperatures of the delivered water varied from 170° to 280° Fahr. More recently, inspirators have been constructed capable of supplying locomotive boilers with water drawn at 150° Fahr. of temperature.

Tangye's Special Steam-pump, with Key.—But few modern inventions have, in the course of a few years, received such patronage as the Special Pump illustrated in longitudinal section, Fig. 24. The great advantage of this pump is that it is double-acting. After it is started, it catches up the water and delivers it into a boiler in a constant stream, and not in intermittent quantities like the ordinary engine-pump. It is capable of keeping up a constant and steady flow of water, and it adjusts itself to the fluctuations in the pressure of the steam. It can be regulated to supply a boiler with water at the same rate at which the water is evaporated and consumed. The motion is known as a "tappet" motion; that is to say, it is one in which

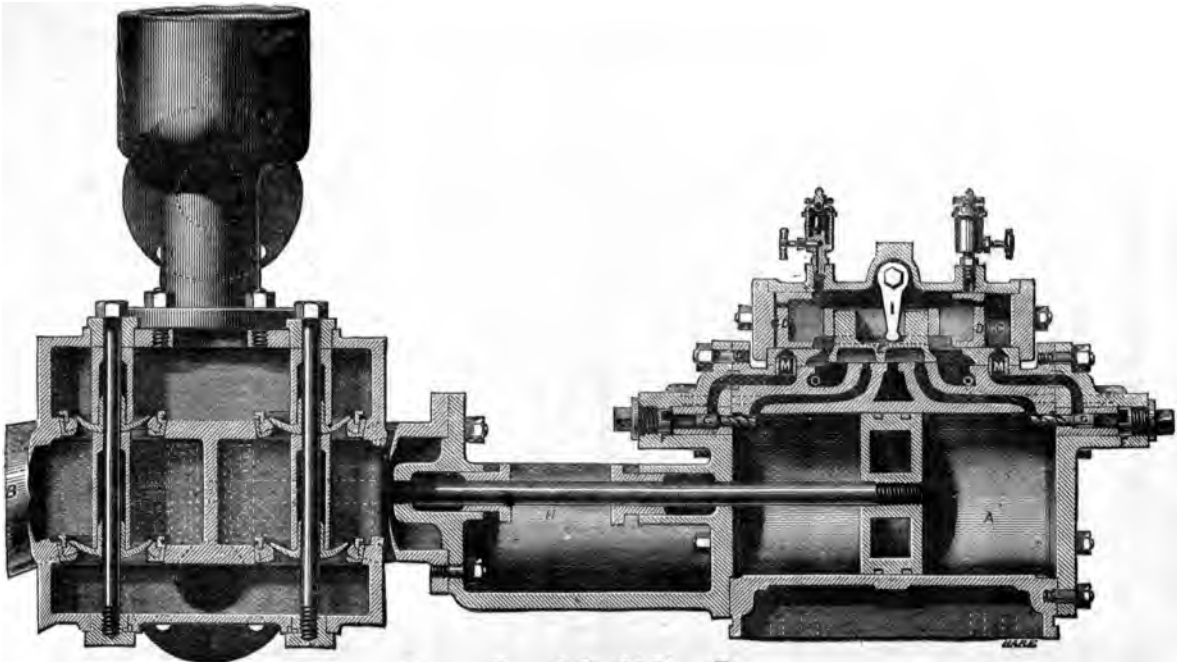


Fig. 24.—Tangye's Special Steam-Pump.

the movements of the valve are regulated by its coming into contact with adjustable lugs, with cambs, and with a reversing-valve.

The key to the pump will enable those who have not yet had experience of it to form an acquaintance with the pump. The steam-cylinder and the pump-cylinder, A and B, are placed in a line with each other, and they are connected by distance-pieces H, the end-flanges of which form the covers for the two cylinders. The steam-cylinder A is made with a double set of steam-passages, one pair of these passages leading from the slide-valve face to the ends of the cylinder in the usual way, and the other pair extending from near the ends of the steam-chest to the inner ends of small cylindrical chambers formed one on each cylinder cover, F F. Each of these chambers is fitted with a reversing-valve G G, which closes an opening in the cylinder-cover: these being—except when moved by the piston—kept against their seats by the pressure of steam on their backs, the outer ends of the valve-chambers being placed in free communication with the steam by small passages.

The slide-valve E covers the exhaust-port and one pair of steam-ports, and it is made of the section shown, so that when it is removed to the right, steam is admitted into the right-hand port and *vice-versâ*. The valve is shown in the engraving in the position which it occupies when steam is being admitted into the left-hand port; the other port being placed in communication with the exhaust. On the back of the valve are a pair of lugs fitted between two collars, formed on a spindle connecting a pair of plungers, D, D, which work in the cylindrical portions forming the ends of the

valve-chest, C C, and into which the second pair of steam-ports, M M, open.

The plungers, D D, are for the purpose of shifting the slide-valve; and they are made to work comparatively free, so that sufficient steam will pass them to form a cushion at either end alternately.

When the pump is at work, the finger I of the starting-lever remains stationary, as the valve does not move far enough to touch it.

The action of the apparatus is very simple. Supposing all the parts to be in the position shown in Fig. 24, the piston will, when steam is turned on, move from left to right. On arriving at the end of its stroke, it will open the reversing-valve G in the right-hand cylinder-cover, thus placing the second right-hand steam-passage in communication with the right-hand end of the cylinder; and consequently, owing to the position of the main-valve, in communication with the exhaust. This being the case, the pressure is removed from the back of the right-hand plunger D, connected with the main-valve, and the pressure of the steam on the inner-side of the plunger then forces the latter to the right, the slide-valve being of course carried with it.

By this movement, steam is admitted to the right-hand end of the cylinder, and the left-hand end is placed in communication with the exhaust. The piston then performs its stroke from right to left, when the operations already described are repeated at the other end of the cylinder.

The action of the valve is not the same in all the Tangye pumps. The section, Fig. 25, exhibits an improved form of reversing valve, E, K. It will be seen that these valves are placed in the passage of the

steam cylinder instead of in the covers, and that they work in a direction perpendicular to that of the piston; the object being to render the valves under all circumstances absolutely certain in action. The piston, on arriving at the end of its stroke, and its edge being slightly bevelled, will lift the improved reversing valve off its seat. This removes the pressure from the back

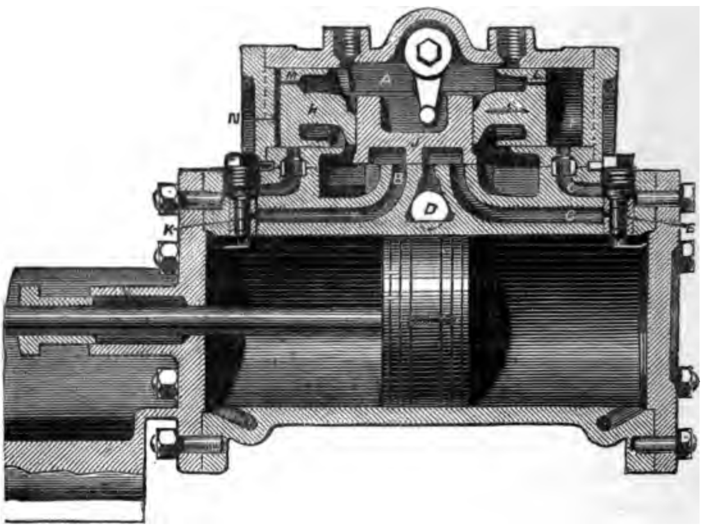


Fig. 25.—Tangye's Special Steam-Pump.

of the right-hand plunger connected with the main-valve, and the pressure of the steam on the inner side of the plunger then forces the latter to the right, the slide-valve being of course carried with it. By this movement steam is admitted on the right-hand end of the cylinder, and the left-hand end is placed in communication with the exhaust. The piston then per-

forms its stroke from right to left, when the operations described are repeated on the other side or end.

Starting the Pump.— Before starting a Tangye-pump, the cylinder should be warmed by blowing steam through it and out of it by way of the waste-water cock. The lever I, Fig. 24, then may be worked by hand backwards and forwards a few times, not for the full stroke, but for a short portion of the stroke only, so that all the water may be blown out of the passages, and that a regular temperature may be obtained throughout the working parts. Should the piston, at any time during ordinary working, instead of making a full stroke, travel to and fro at one end of the cylinder, the plug F at the opposite end of the cylinder should be unscrewed and the piston-valve blown out by steam, cleaned and returned to its place. A little grit will sometimes prevent its working properly. For lubrication, suet should be used, because it is better and more genuine than tallow or oil, and is much more economical in cost than either of these.

Delivery of Supply.—To ascertain the quantity of water that a pump will deliver, it is necessary to calculate the solid or cubical contents of that part of the barrel in which the vacuum is produced and to reduce it to some standard measure, and to multiply this by the number of strokes made in a given time. If a pump-ram is nine inches in diameter, and makes an effective stroke of 18 inches, its performance may be found either for each stroke or for a number of strokes. The pump illustrated above has a capacity of 1,145 cubic inches, which, divided by $277\frac{1}{4}$ cubic inches, the volume of an imperial gallon $=$ 4·13 gallons: that is, supposing the ram to be at the end of the

outdoor stroke and the pump full of water, it would displace 4·13 gallons by making the indoor stroke. Therefore it is clear that at the rate of 10 strokes a minute $41\frac{1}{4}$ gallons would be displaced or pumped out per minute; and at the rate of 100 strokes a minute, 413 gallons will be displaced, or 60 times 100 strokes; for the work of one hour $= 413 \times 60 = 24,780$ gallons. As a gallon of water weighs 10 lbs. the total weight delivered in the hour would amount to $(24,780 \times 10 =)$ 247,800 lbs.

CHAPTER XIV.

CAUSES OF FAILURES.

It is not an unusual occurrence for a stationary engine to break down by more causes than one, and by causes unknown to enginemen.

One man may have a list of failures, an extensive list, which he might show to another man, in the belief that it exhibited rather extensive experience in breakdowns, and yet he may find himself face to face with facts and incidents quite beyond the range of his experience. It is highly commendable to find out the cause of a success, but, it is only by knowing *how* and *where* engines have failed, that a man can be made a complete engineman.

As things are at the present time, when almost any man who has the slightest pretence to an acquaintance with engines can procure a berth to look after an engine, it is our duty to try and meet the evil. That there are men in charge of engines who know nothing excepting shovelling coal, is a fact; and they are not to blame for getting into the engine-house to change the shovel for the "STOP" and "STARTING" lever. That being a fact, for which at present there is no remedy, the following list of failures and the causes may be of value to those who feel their need of information. A man is

before us who is well aware that hot water, if poured into a glass, will crack it, spoil it, break it, and still he turns steam, which is hotter than the water in a kettle, into a cold cylinder and cracks that; which may cost two or three hundred pounds to put right again. Here is a man who knows that if the water in the kitchen pipe is turned off suddenly, he will have in all probability to pay the plumber to patch the bursted water-pipe, and still he will go to his engine and shut off a stop-valve suddenly, and is surprised that the steam-pipes crack and the boilers burst.

We will give some cases which have come before us.

An engineman broke in halves the beam of an engine of 80 horse-power, by allowing the injection-water in the condenser to augment until it entered the cylinder. The water, being incompressible, resisted the "down" stroke of the piston, the momentum of the fly-wheel resisted the "up" tendency of the water, consequently the weakest point between the crank-shaft and the condenser was found in the centre of the beam, where it parted, and it came down with a great crash to the floor. This accident was caused soon after starting by not so regulating the supply of water to the condenser that the air-pump could discharge it into the hot-well.

An engineman broke a beam in halves, not noticing that the foot-valve of the condenser was out of order, which disabled the pump.

An engineman broke a beam by allowing blocks of wood to lie about the engine-house, until they were accidentally knocked into the pit of the fly-wheel, where they glided between the rim of the wheel and the masonry, forming a kind of break-block against the steam on the piston.

An engineman blew an excessive quantity of steam through the cylinder-jacket, and so heated the water in the condenser, that it caused the air-pump bucket to expand, and created sufficient friction to bend the pump-rod.

An engineman, by not blowing sufficient steam through the jacket, split the cylinder by admitting steam into it before its temperature had been sufficiently raised.

An engineman started his engine without examining it properly, causing some waste to be the means of breaking a pair of geared wheels, which incurred an enormous amount of delay and expense to the proprietor.

An engineman, getting the chill off a slide-bar and slide-block, caused them to expand and attempt to grip. The slide-bar seized down upon the block, and the block seized up to the slide-bar. After he had oiled it, it did not appear to improve, the two faces fitting so closely as to exclude even a film of oil; and the engine was compelled to run at half speed for a time. This mishap was caused through the refuse in the oil blocking up the pores in the worsted trimming, and thus preventing the oil from lubricating the bearing.

An engineman allowed the lid of an oil-box to fit air-tight, and consequently the trimming would not act properly. He retrimmed it and still the bearing would get hot; he altered the trimmings several times, but his efforts were of no avail. The mill, however, had to be kept going to finish some important work, and by the end of the week the journal and the brass were considerably cut. The engine was of course

delivered over to the engine-maker for repairs. It may be asked how it was that the lid became tight so suddenly. We have simply to refer to the fall of the lid of the box on to the edge every day, by which the inequalities on the two faces were smoothed away, in time making a perfect air-tight joint, excluding the air from forcing the oil down the worsted pores, and therefore if a box was full of oil and the lid was air-tight the journal would run without obtaining any oil. Scores of journals run hot through the boxes being air-tight, and the remedy is seen too frequently applied in the wrong place, namely, by filing a notch in the box edge. Sometimes this is made sufficiently deep to make it impossible for the fall of the lid to obliterate it; but even then there is danger of its becoming air-tight, especially when tallow is mixed with oil. The proper way is to admit the air through the centre of the cover by a hole, in which a small piece of sponge should be placed to prevent the dust of the engine-house entering the box and clogging up the siphon-cup.

An engineman took his feed-water from a brook, and allowed some chips to enter the engine-well, which were drawn up the suction-pipe into the pump, and, getting under the clack, disabled it. Time was lost in attempting to get the clacks to fall by pouring cold water upon the pump to condense the steam under the valve. Sometimes valves are held up by the steam in this manner when they are seated too high and require lowering. The boiler, becoming short of water, the engine had to stop, and the top clack being up, the second clack could not be examined, so that the steam had to be blown off from the boiler and the works stopped, by

the absence of a strainer in front of the well, and by want of a head that could see the chips floating in the brook and the same chips underneath the clacks.

An engineman was short of steam, and was not able to pump a sufficient supply of water into a large tank. Complaints were made, and he had the affair in his own hands. But the pumping did not improve, and the man stated it was all the fault of the boiler, and when the boiler was inspected it was found that the brick-work all round the front was broken, and therefore it was drawing air there. So soon as this was mortared up and made air-tight, the draught in the chimney was restored. The fire depends upon the chimney draught, and not upon air that can steal into the flues through dilapidated mortar and masonry.

An engineman became short of steam through allowing the flues to be choked up with soot.

In consequence of an engineman not looking after the cleaning of his boiler it was made up with stone deposit.

In consequence of an engineman not making examination before making a fire under a boiler, he burned it, by its being short of water. The boiler had been filled up overnight, but it had sprung a leak, no doubt through the sudden contraction of the plates at the time or after the fire had been drawn, and through the fire-door being open and the damper up.

An engineman washed a boiler out and filled it with water again, and the next morning he made the fire up in the usual way. After a little while, when he began to think the steam should appear, he perceived something smoking on the top of the boiler, which he found to be an old bag, and directly afterwards he found the

flue red-hot. Where could the water have gone? It went out through the blow-off cock, which was not shut close. All blow-off cocks should be carefully watched, because they may sell a man at any time when he least expects it, through ordinary wear and tear.

An engineman was blowing steam out of two boilers into a third, in order to have the third in working order quickly. When he considered that there was sufficient in the third boiler, he shut the communicating stop-valve suddenly, and burst the other two. When steam is stopped in its motion, it will of course rebound like anything else—like a stone, if you will, or a shot.

The force of elasticity produces motion in the steam, and it has a tendency to continue that motion until acted upon by some extraneous force. As soon as the stop-valve was shut in the instance referred to, the current of steam towards the valve was momentarily accumulated upon the valve, and the pressure correspondingly increased. The result was that the current of steam reacted into the boiler, bringing to bear sufficient power and pressure upon the water to burst the boiler.

An engineman, by opening a stop-valve suddenly, split a large steam-pipe, and consequently disabled the engine for two days, there being no spare elbow, and there was nothing else to do but to wait for one from the foundry.

The cause of this mishap, apart from the engineman's want of experience, was due to the steam driving the condensed water in the steam-pipes before it, to an elbow or corner, where the water, being pressed by the velocity and pressure of the steam, acted as a

bullet, and the steam as powder. This mishap stopped a flour-mill, and put the miller to much inconvenience; but neither the man nor the master was aware of the true cause.

The sudden expansion of steam has been used to throw balls out of a cannon. Now, water, being incompressible, is, in a sense, as solid as iron confined in a pipe, and therefore when a stop-valve is suddenly opened, and the pressure and velocity of the steam is opposed by water in the pipes, it is only reasonable to expect a smash.

Lastly. When the mind possesses no scientific principles for its guidance every act is invested with doubt, and any accident which may be caused through ignorance is surrounded with mystery.

CHAPTER XV.

STEAM-BOILER EXPLOSIONS.

ALL boilers, experience informs us, become gradually weakened by the working of destructive agents from the moment they are constructed till the time they are broken up. The progress of deterioration greatly depends upon the quality of their material, the design, and the amount of personal attention given to them; and therefore the progress of deterioration cannot be estimated at first sight. We are supposed to have more experience in the construction of steam-boilers than any of our predecessors. Yet, from time to time, we find boilers give way without a moment's warning, in consequence of imperfections or of mismanagement. There is not an atom of truth in many of the nonsensical hypotheses which are sometimes advanced to account for such accidents. The most common cause of boiler explosions is corrosion, which attacks a boiler, outside and inside. External corrosion may be occasioned by negligence of the most culpable description, or it may occur and work destruction through the ignorance of those who set the boiler in the brickwork. Culpable negligence is exhibited when the boiler plate is exposed to the atmosphere; the corrosion is then a slow process, but nevertheless it is a wasting away of the iron and its effects cannot be winked at.

It is seen when the water from the leaky gauge-cocks is allowed day after day to run down the front of the boiler. It is seen when a manhole-joint leaks and the condensed steam is allowed, from one week's end to another, to run down into the brickwork by the side of the boiler. It is seen when the condensed steam from the safety-valves, month after month, does the same thing. It is seen when the fireman or the engineman damps the ashes when they are close to the plates. All these occasions for corrosion are open to view; and it is well known that such leakages are causes of corrosion, more or less fatal according to the composition of the water. But the worst kind of corrosion is that which is due to the setting of the boiler on brickwork in such a way that the moisture from below and the drippings of water from the mountings above can find a lodgment in it. There, out of sight and out of mind, it eats the plate away to the thickness of sixpence. This is external corrosion, pure and simple, as it has not anything to do with the wear and tear of the boiler.

To prevent corrosive action of this kind all that is necessary is to set the boiler upon fire-lumps, as illustrated in Plates III., IV., V. Again, when boiler-mountings are permitted to leak, and the water runs down the side of the boiler, it is absorbed by the soot in the flue, and formed into a paste, which in contact with iron is a formidable enemy, and will reduce a new plate to a skeleton in an incredibly short period of time. The plan of building in a boiler with brickwork at both ends is out of date; so is any plan that savours of making a comfortable ledge for water or condensed steam in contact with iron.

Internal Corrosion.—This form of wasting away is not so rapid as external corrosion, when left to its course. But, provided that there were no such effect taking place, then the boiler internally fired would sooner or later succumb to internal corrosion, either extensive or local. The action of corrosive agents internally is chemical, galvanic, and mechanical. It is chemical when its effects resemble that of the work of ordinary rust—uniform. It is galvanic, when the stays' heads are eaten off, or when pit-holes are formed in the tubes and boiler-plates; or when the end of a gauge-glass is consumed in a very short time; galvanic action is very prevalent in boilers fed with water from a surface-condenser. Not long ago a hammer was taken out of a surface-condenser, having the soft portion of the eye eaten in holes, but the steel faces were untouched. It had been in the condenser nine months. Galvanism is a species of electricity excited, not by friction, but by establishing a communication between two different metals through the medium of a liquid: it is capable of producing an intense heat, and it also possesses energetic decomposing power. Mechanical action is exhibited by grooves, which are formed by alternate bulging and straightening, and is assisted by any acidity which may be present in the water. The mechanical action strains, frets, and fatigues the iron until the skin is broken, and the rapidity of the fracture is hastened by the action of acids in the water, which attack the most susceptible and sensitive parts, until a division or groove is made, when the water leaks through into the furnace or the flues. Grooving is generally found in the roots of angle-iron and flanged plates, and at the

longitudinal lap-joints of Cornish and of Lancashire boilers. This grooving action is due to the strain put upon a boiler whilst at work. It is quite certain that the contraction and expansion caused by opening the door for firing, and by urging the furnace, are very unequal, and cause unequal action of a serious nature; and although this action is known and specially dealt with by our very best boiler-makers, who employ "pockets," "gussets," and welded-in water-tubes, for insuring safety, yet the object may be frustrated by many circumstances beyond control. And what are they? Not electricity, not the spheroidal theory, nor the generation of explosive gases, nor a greater deterioration in the plates than what was expected under ordinary wear and tear. None of these things; but the want of *nous* on the part of the attendant. Overheating, overstraining, accumulation of deposit, wedged safety-valves, the conversion of the static pressure into a dynamic force.

Overheating may not cause a blow-up at the time, and it is well that cold water turned on to heated plates is not of itself capable of being at once converted into a large body of steam; otherwise many more boilers would have been burst. An engineman not long ago found the tube in a Cornish boiler overheated, and, fearing the consequences of his negligence, he chose to risk a kick from his boiler, rather than insure one from his master, and turned all feeds on, and so regained the proper water-level. But the mischief never ends here when such occurrences are smothered instantly. It is a well-known fact, if a piece of good ductile wrought-iron is heated to redness over a blacksmith's fire and then cooled suddenly in water, it becomes brittle and liable to snap. What

is there to hinder a piece of boiler furnace from becoming brittle when suddenly cooled by a pump throwing cold water upon it? The plate may support, in its crystallised condition, a crushing pressure for a time, but it will be liable to snap at any moment, as the atoms of which it is composed are loosened and disarranged, when any extra degree of expansion—tensile strain—may tear them asunder. When iron is overheated it becomes speedily oxidized, and its tenacity and cohesive force much reduced.

Not infrequently, over-heating is caused by the gauge-cocks being in a filthy condition, and not workable, the check taps being as fast as a rock—the boiler being practically charged like a cannon, ready at some convenient season to admit daylight through the roof of the boiler-house.

Sometimes overheating occurs in consequence of the boiler suddenly springing a leak, or bursting a tube. When such a surprise happens, an active fireman or engineman rakes the fire out of the furnace before much mischief is done. An engineman filled his boiler up after washing it out, and went home. He returned as usual next morning, and lighted the fire; presently he had a suspicion that all was not right, and upon his examining the boiler it was found to be empty. He examined the blow-off cock and all the mud-plugs about the boiler, but he could not discover any trace of the missing water. Where was it? In another boiler that had dropped its steam during the night, a vacuum was formed above the water, when the water of the boiler which had been filled was drawn through the feed-pipe, which was defectively arranged.

Overstraining may be occasioned by tampering with

the safety-valves, hanging weights on the lever, or wedging the lever down, in order to obtain a good pressure of steam. Or it may arise when, the boiler-power not being equal to the demand for steam, the fires are urged; for, although steam may not blow off at the valves, and the valves may not be locked, yet there is likely to be an excessive degree of expansion in the plates. This kind of straining takes place when steam is taken from the boiler to supply an additional engine. At the best of times, the expansion of the furnace, or the iron in contact with the fire, is very much more per foot than in the surrounding plates. Boiler plates in contact with the fire deteriorate not necessarily in proportion to the time they have been at work; but in proportion to the amount of heat that has passed through them in a *given* time. The heated plate depends for its preservation upon the water taking the heat out of it, as fast as it enters from the furnace; but, in the absence of this condition, it becomes overheated and evaporation is actually impeded, as the water is driven off by excessive heat, which produces excessive expansion, and, in consequence, buckling and grooving, and becomes the employer of the caulking tools, and the arch destroyer of the boiler.

Take an internally fired boiler, urged by a fierce fire. The flue-tube expands; it becomes longer; and it therefore pushes both the back and the front plates outwards. But if the end plates will not spring, then the tube becomes a bow, and the lower side is excessively strained by compression. Take a willow stick, with wood discs on each end, and bend it as a tube is bent, and as the fibres of the stick arrange themselves

to suit that position, so do the fibres of the iron; mark perpendicular lines at the end of the discs and note their altered position under the strain, and the probability is you will learn why grooving and fracture take place in the root of the angle-iron which holds the end plate to the shell of the boiler. Any kind of over-straining may be caused by unskilful enginemen. They may, for instance, blow off a boiler whilst it is very hot, and then turn cold water into it, either from the main or the tank—the intention being to wash it out. In some districts, such treatment, it is supposed, brings down a large quantity of scale. The scale is suddenly cooled and contracts more quickly than the boiler-plate, and therefore it is split up in consequence of the capricious manner in which contraction takes place amongst its own particles. Here there is not a thought as to how the contraction affects the boiler-plates. Of course they are affected like the scale, but upon a scale of greater magnitude, and extending over a larger period. The immediate effect is to produce leakage in the joints and the old fractures. The second effect is to make work for a boilermaker with a caulking-tool; the third effect, following from the second, is to cut the skin of the boiler; the fourth effect, following from the third, is corrosion; the fifth effect is that leakage, caulking, skinning, and corrosion are always at work; the sixth effect is a blow-up. It is thus seen that over-straining may be caused by an excess of heat, or by an excess of cold.

Accumulation of Deposit or Scale.—Too great an accumulation of scale, either general or partial, prevents the proper distribution of heat to the water, and the heat of the metal is then increased to too great an

extent. The ductility of the iron is changed, and it is caused to bulge and yield to the pressure.

Most kinds of water contain solid matter in solution or in suspension, and as the water is evaporated the solid matter remains and finds a resting-place on the top of the tubes or on the crown of the furnace and on the sides of the boiler. The nature of the deposit varies with different kinds of water. There is a stone deposit, and a floury deposit. The former is sometimes called boiler-stone. The quantity of stone in solution in some waters, such as is taken from a brook in dry weather, or pumped from a well where the surrounding material is sand or rock is very considerable, varying from 50 to 150 grains in a gallon. Every particle of solid matter that enters the boiler must remain there unless carried off by priming, scumming, or blowing off. The deposit must, if neglected, become a great evil. In fact, some boilers when opened have been found half full of solid stonework. It is found that the layers of stone deposit sometimes arrange themselves in such wise as to leave interstices to which the water can penetrate. When the water finds its way through these openings to the hot plate a local explosion takes place, which loosens the scale for some distance round. These explosions produce a rumbling commotion, and are not infrequently followed by the bulging of the furnace plates, and a trembling of the whole structure. It is often remarked by a witness at an inquiry into the cause of a boiler explosion that before the accident a rumbling noise was heard. Let us try to find an explanation for such a phenomenon.

If steam of a high temperature is turned into a tank full of cold water, it will carry a considerable quantity

of water before it, which will strike the side of the tank with great force. In fact, if the tank is not very strong, it will become bulged outwards, and it may ultimately be fractured. The rumbling sound is not in the water or the steam. It is the muffled ring of the metal, produced by blows from the water. Heat is the agent which produces the mischief. If the incandescent boilerplate is supplied with a given quantity of water underneath a scale, its sudden formation into steam will scatter the adjacent scale and carry the water before it against the top or sides of the boiler. Scale having once been dislodged, fresh local contacts of water with the heated plate take place, and there is then a succession of cone-like forces of high-pressure steam producing a succession of blows, by driving the incompressible water against the crown of the boiler. It is the highly heated and elastic steam coming in contact with water, which produces the mischief. The hot plate is its base; its velocity is due to its elasticity. The energy of the steam is concentrated upon the water, which closes in upon it, and acquires a projectile velocity, as in an injector, so high that the point of impact rumbles under the blow, and the whole boiler gives notice.

The deposit may consist of a floury paste—carbonate of lime. When the deposit is allowed to accumulate in the boiler, the water, more or less, resembles a stir-about, which must be penetrated by the heated water or the steam, in order that it may reach the steam-space.

For this purpose, the water must be raised to a higher temperature than would be required if the water were comparatively clean, and consequently the tem-

perature of the plate is in excess of what it would be under better management.

The accumulation of this kind of deposit does not raise the alarm in the mind of enginemen like a thick layer of boiler-stone, but as a cause of over-heating it is quite as potent.

With portable boilers and locomotive boilers, which change their water by changing the locality of their operations, much comparative experience of the effects of the two descriptions of scales is obtained. Locomotive boilers perfectly water-tight with stone deposit, have, after working for a short time with water forming a floury scale, begun to leak. The stone-scale falls from the tubes and the walls of the fire-box in bucketfuls. If the scale happened to fall off without incurring leakage, the effect would have been attributed to the superior quality of the water. But granting that scale did leave the boiler-plates by virtue of the superior quality of the water, why should it make the tubes and joints open out?

The true cause is the expansion of the heating surface in excess of that which took place while the stone-scale was forming.

Take a pan coated with stone on the sides, and coat the bottom with a paste of flour and water, and after filling it with water, boil the contents. The scale will fall off. The flour paste stopped the heat from passing rapidly through the bottom, and therefore the pan was raised to a higher temperature than usual; and not only is extra expansion caused, but if the paste be too thick, it will cause the bottom to be burned out; or, what is a better illustration of the influence of excessive temperature, the pan will become unsoldered.

When boilers are supplied with water which holds in solution chalk, limestone, &c.—carbonate of lime—they are not so ticklish to manage as those which are fed with water holding in solution sulphate of lime. This salt stops up the apertures of the feed-pipe, and gradually reduces the efficiency of the pump, an effect which alone is no small factor in the causing of a disaster. It is also very troublesome inside the boiler, as it accumulates between flue-tubes, and impedes the circulation of water. It also gets into the perforated holes in the steam-pipes, cutting off the supply of steam. But, more leaking, bulging, and fractures will follow the use of chalk and limestone water than what follows from the use of stone and rock-water.

Once more. We have a vessel half full of sand and the other half full of water, and if we make a hole in the bottom, the water will pass through the sand and escape; if we empty the sand out and replace it with flour, we shall find the water will not pass. We learn by induction that the pores of sand are not so fine as the pores of flour.

When the floury deposit becomes very thick by neglect in removing it, the plates and tubes are raised to an excessive temperature in order to make some impression upon the water. In course of time, the "nature" is burnt out of the iron, and there is then great danger of the furnace collapsing. When an overheated plate gives way, it is generally pressed down —collapsed—showing clearly where the plate had been overheated. A particular feature in the condition of a collapsed flue when crushed by over-pressure, and not weakened by fire, is that the flue is driven in on both sides of its axis.

Wedging down the Safety-valve.—This is a glaringly bad piece of foolery that is seldom harmless. When it is detected, the delinquent should be sharply dealt with. The safety-valves are adjusted to blow off, and to relieve the boiler of an excess of steam which, if it was retained, would distort and injure the permanent arrangements of the whole structure. When the safety-valve is pegged down tight upon its seating, there is no escape for the steam, which augments in force until the resistance of the boiler is overcome, and ultimately the weakest place suddenly yields, and destruction is inevitable. Let us look at the reckless danger of locking down valves, which is done every day. Sometimes the boilers are situated underneath office floors, factory floors, under the streets, the pavements, and the shops; an engineman locks down the valves of a new boiler, just from the maker's hands, and he thinks no danger can happen.

A boiler may be new to-day, and it may be exploded to-morrow under the pressure at which it was guaranteed to stand for several years. A boiler may be injured and weakened in transit between the boiler-maker's yard and that of the purchaser's, and who will say anything about it?

A boiler may be fixed in its position, and for want of proper support, its back is broken. A boiler may be properly tested, and the test may be overdone; so that after the test it is a weaker boiler than it was before it was tested, the strain it has suffered remaining undetected. A boiler may be weak before it is tested, and the weakness aggravated—not cured. A boiler, after it is subjected to intermittent expansion and contraction for a time, may open a hidden flaw in the plate.

A boiler may be made to sell, not to work under the most reasonable pressure. A boiler may have been burnt by an engineman and blown up by his successor in ignorance of the defect. But, however sound the original test and examination may have been, it is no answer to the folly of wedging down safety-valves.

The conversion of the static pressure of steam into a dynamic force.—When water flows through a pipe, if the tap be shut suddenly one will hear a sharp click and a rattle, and if the pipe be not very strong, it will burst.

Then why should we not burst a boiler in the same way in ignorance? Not with water, but with steam. The thing has been done, and has ended in a fearful loss of life. The steam from two boilers was allowed to flow into a third, and when the operation was finished the stop-valve was suddenly shut, and the steam that was issuing from these boilers being suddenly arrested and stopped in its motion, struck back forcibly into the boilers, like the water in an hydraulic tube, and impinged, as would a solid body, on the boiler-plates and burst them. There can be no question about the sudden retrocession of steam giving rise to an enormous force. By such force the bends and elbows of cast-iron and copper steam-pipes are frequently cracked when the valves and cocks are suddenly closed.

It may safely be concluded that the primary cause of boiler-explosions may be traced to corrosion of the plates, either as a uniform wasting of the surface, or as rapid local decline, rendering the plate too weak to bear the ordinary working pressure. The idea of high pressure is only a relative one, and can have reference only to the comparative strength of a boiler on which

the pressure is exerted. A boiler may be as safe with 150 lbs. pressure as another with 50 lbs., and even be less liable to burst. High pressure exerted in a vessel of small dimensions may not amount to more than a low pressure in a proportionately larger vessel. In every boiler, steam of too high an elasticity for the resisting strength of the boiler may lead to an explosion, and of all things, great and small, there is none so quiet, so insinuating, and so certain in reducing strength as corrosion: especially external corrosion, when the subtle "sweating" of the plates underneath, in mixture with soot or with moisture, is not easily suspected. It attracts not the unskilled engineman, it does its work without a rumble, or a fracture, or a blister. What fever, or the flush upon the cheek, or a catching cough is to the human frame, corrosion is to a boiler—a solemn warning.

CHAPTER XVI.

THE INDICATOR AND HOW TO WORK IT: WITH ILLUSTRATIVE DIAGRAMS.

INDICATOR.

VERY accurate information respecting the character of steam and its behaviour in the cylinder, together with the condition of the valve and the motion, can be obtained by means of this instrument, originally invented by the celebrated Watt, and subsequently improved by Richards, Richardson, and others.

There is nothing so important about an engine as keeping the valve-motion in good working order. When the lead is absent, an unsteady action in the cylinder is set up; when it is slightly deficient, a portion of the stroke is performed with steam of a pressure much under the boiler pressure; when it is intact, and of the right amount, the engine works under the best conditions and with the minimum quantity of steam. How far this latter condition is attained can be found out by means of the indicator without removing the steam-chest or exposing the valves.

The instrument is not so highly appreciated as it deserves to be, for few private owners of engines know anything of its capability for telling tales, and the enginemen who know how to work it are few and far

between. Fig. 26 represents a normal indicator diagram. It was taken at a slow speed, when the steam and the valve had sufficient time to perform their movements with great regularity and precision, more than when the engine runs at a higher speed. To make such a diagram the valve must be in excellent working order and well trimmed.

The indicator consists of a small steam cylinder,

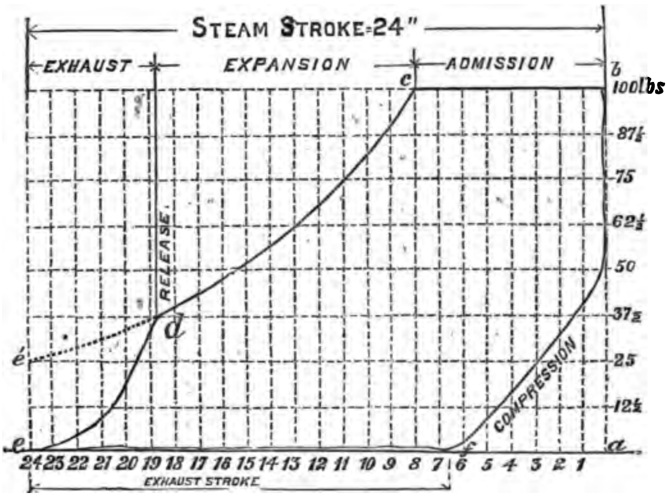


Fig. 26.—Normal Indicator diagram.

fitted with a piston held down with a spiral spring. The instrument is screwed into the cylinder cover, and when the communicating cock is open to the steam in the engine-cylinder it acts upon the piston of the indicator, which is fitted at the top, outside, to a lever, which carries a pencil in contact with a piece of metallic paper coiled round a barrel fixed to the left in

a vertical position, having upon its face a graduated scale.

The barrel turns on a vertical pivot, on which it receives a reciprocating movement by means of a cord attached to it at one end, and the other end to the cross-head of the engine; the movement then of the barrel represents the stroke of the piston. The movement of the small indicator-piston represents the pressure of the steam at every point of the stroke. The movement of the either is independent of the other. When steam is admitted to the indicator, the piston rises and falls in obedience to the pressure underneath it, proportionally compressing the spring, and the pencil rises and falls. The barrel is acted upon by the cord, and revolves to and fro. It should be stated that within the barrel there is a kind of watch-spring, which turns back the barrel to its original position as the engine finishes the reverse stroke. It should also be understood, that whilst the engine-piston moves, say, two feet, the length of a stroke, the motion of the barrel can be reduced by a system of levers or by a reducing-wheel to suit the length of the diagram required.

Richardson's continuous indicator is represented in Fig. 27. In the interior of the barrel, or paper-cylinder, there is a receptacle for a roll of paper, the end of which is brought out through a slot. It is thence passed round the cylinder, and is inserted again into the interior, when it is caught by a slotted roller, which is worked in one direction during the motion of the paper cylinder. When the diagram has all been taken, the length of paper can readily be pulled off the roller.

An indicator, Fig. 28, has recently been invented

Fig. 27.—Richardson's Continuous Indicator.

by Mr. E. T. Darke. In this instrument, every means has been taken to reduce the weight of the moving

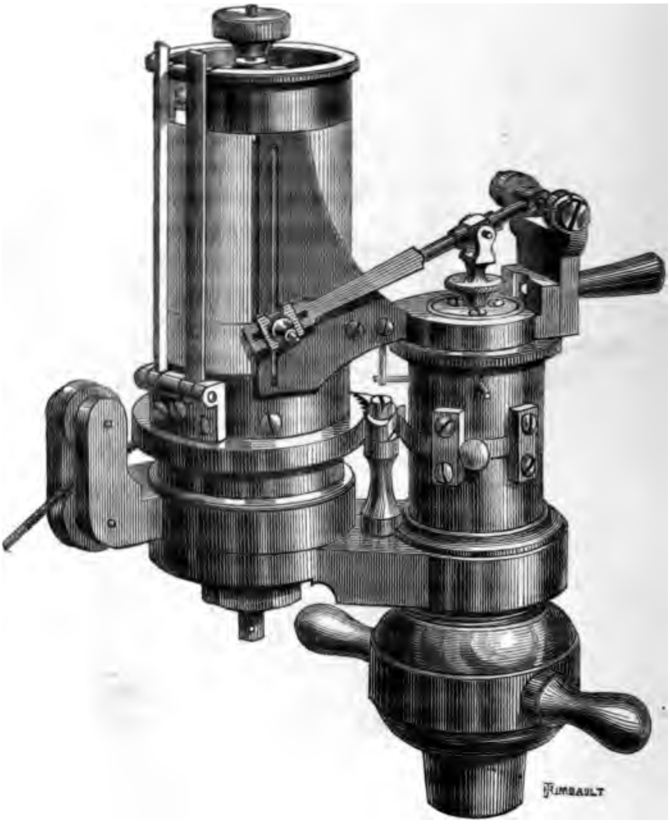


Fig. 28.—Darke's High-speed Indicator.

parts, and consequently their momentum, so as to obtain more correct diagrams at high speed than can be taken from other indicators. The piston has an area of only

$\frac{1}{4}$ square inch. The spring is very small in diameter, the piston-rod is hollow and short. The stroke of the piston is from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch, and the greatest length of diagram is $3\frac{1}{2}$ inches. The pencil-motion is made of one piece of steel, fitted at one end to and sliding in a hollow cross-head on steel centres, and carrying at the other end a small sliding-block, through which the pin, or pencil as it may be called, passes. The pin moves upon the paper drum through a slot or guide, swivelled to the top of the steam cylinder of the indicator. There is, of course, provision made for the sliding of the pencil in the pencil-arm, to enable the pencil to follow a straight upright line, whilst the arm moves radially. The paper-drum is made available for the reception of the indicator-paper, which is placed in the interior in a roll—a continuous sheet—and may be drawn through a slot at the side as required, and torn off when a diagram has been taken.

In fitting up the rigging for obtaining a diagram, long tubes should be avoided. When used they should not be smaller than the piston of the indicator, but slightly larger, so as not in any way to impede the motion of the steam. Bends in pipes should be easy; pipes should be as short and direct as is possible, as each inch of pipe occasions a perceptible fall of pressure between the cylinder and the indicator.

When the pipes are connected to each end of the cylinder it is a good plan to have a three-way cock at the point where the horizontal pipe connects with the vertical one leading up to the indicator.

It is necessary, when taking diagrams at all, to take them from both ends of the cylinder.

The assumption commonly made that, if the valves

are set equally, the diagram from one end will be like that from the other, is erroneous. The speed of the piston is, at the outer end of a direct-acting engine, from 35 to 66 per cent. greater than at the crank end; the difference varying according to the degree of angular vibration of the connecting-rod. In beam-engines the speed of the piston is greater at the upper end of the cylinder. These and other causes, as port, lead, opening and closing, will make a difference in the diagrams from opposite ends of a cylinder. On horizontal cylinders the best place for the indicator is on the top, in a vertical position by means of piping. If it cannot be placed there, some convenient position must be found for it, by means of pipe rigging, care being taken to avoid as many bends as possible. On vertical cylinders it is often attached where the oil cup is fixed, but at the lower end it is frequently necessary to drill a hole in the cylinder between the bottom and the centre of the cylinder. Sometimes with double cylinders having parallel motion, it is necessary to drill a hole in the side near the top as well as the bottom. It would be well that these holes were always drilled in the shop, so that the burr could be removed properly and the drillings cleared out of the way. The motion for working the indicator barrel, by means of the cord, which should be hard and inelastic, may be taken from any part of the engine which has a motion coincident, or similar to that of the piston motion. For a beam engine, a point on the beam, near the beam centre, or on the parallel-motion rods where these are employed, will give the proper motion. The motion may be taken from the cross-head of an horizontal engine. A simple plan, and a very good one, is to suspend a piece of

wood from the ceiling, or from anything above the motion, so that its centre of gravity, or point of rest, is right over the point where the cross-head is when it is in the middle of the slide-bar, or rather when the piston is in the centre of the cylinder. The lower end of this slip of wood—or it may be of iron—is attached to the cross-head by a pin, projecting through a slot in the board, in which it should work nicely but not tight. While the lower end of the board, when attached to the cross-head, makes a stroke equal to that of the piston, the upper end remains stationary, and therefore between these two extreme points there is one to be found that will be equal to the required motion of the indicator barrel—that is as a rule about five inches. To this point a small coupling-hook can be attached on which the loop end of the cord can be placed and the other end attached, of course, to the barrel. When the cord is too long it is best to reeve it through a strip of brass having three holes in it, which is better than making a knot in the cord.

Another way of obtaining the required motion is to use a kind of weigh shaft, supported in two bearings, and placed exactly over the cross-head and fitted with two arms, one longer than the other, the long arm being connected by the cord to the cross-head, and the short arm to the indicator. The short arm must be keyed in such a position that when the piston is in the middle of its stroke it will stand at right angles with the direction of the cord. The direction of the cord may form any necessary angle with the horizontal line, but must be at right angles with the weigh shaft.

On locomotives, it is usual to take the motion from the cross-head, which motion is reduced from that of

the cross-head to that of the indicator somewhat in the manner described above, with a board suspended from a point in the hand rails on which is a proper lever that can be clamped, or otherwise fastened. To this lever the cord can be connected at a point sufficiently near to the hand-rail to give the required reduction of motion for the paper. The cord can in all cases be led into a horizontal direction by means of pulleys to suit the position of the indicator barrel.

On oscillating engines, the motion may be taken from the brasses at the end of the piston-rod. If the stroke is long it is sometimes difficult to reduce this motion to that required for the paper, and in such cases it is necessary to take the motion from an eccentric on the main shaft to a point as near as possible to the trunnion, and thence to communicate to the indicator. There must be no slack in the cord, and the barrel must not touch the stop.

To take a diagram by the indicator, from the cylinder of a non-condensing engine, the first thing is to revolve the barrel. The pencil traces a straight line, which is called the atmospheric line, or the line which corresponds to the absolute pressure of the atmosphere, 14·7 lb. per square inch. The cock is now opened, and steam is let into the barrel of the indicator. It does not signify at what point of the stroke this is done; but to simplify the explanation, we will suppose that it is done at the commencement of the stroke *a*, Fig. 26. The steam then instantly drives the piston, and with it the pencil, upwards. The pencil rises as high as the pressure in the engine-cylinder will lift it, to the level *b*, where it remains so long as the pressure underneath it remains unchanged. Meanwhile the

barrel is pulled round, and no other change takes place until the point *c* is reached, where the steam is cut off by the valve, which closes the steam-port. Expansion commences, and the pressure in the cylinder is gradually reduced to the pressure indicated by the point *d*. If steam of 100 lbs. total pressure, or 85 lbs. effective pressure, in the cylinder is cut off at 8 inches of the stroke, and is allowed to expand through another 8 inches, the volume of the steam is doubled, and the total pressure is reduced one-half (to 50 lbs.), giving an effective pressure of 35 lbs.; and if it is allowed to expand through another 8 inches of stroke, the volume is trebled, and the total pressure is reduced to one-third. This law of the expansion of steam is known as Boyle's law, or Mariotte's law, after the name of the discoverers; and it constitutes the basis upon which calculations of the expansive action of steam are made. When it is known what the pressure of steam is in the cylinder before the valve closes the port, the pressure of the steam when the valve opens the port for exhaust can be calculated. At *d* the pencil suddenly drops, which is owing to the valve having opened the exhaust-port to the atmosphere or the condenser, and at once joins the atmospheric line at the eduction corner *e*. Now this indicates that the exhausted steam is cleared out of the cylinder. If there were any steam in the cylinder of a higher pressure than that of the atmosphere, it would act upon the piston of the indicator and prevent the pencil falling so low as the atmospheric line.

Should the exhaust-steam meet with any obstruction, as too much inside lap, or contracted passages, the resistance will be shown by the elevation of the pencil

above the atmospheric line, which represents a clear cylinder. From *e* to *f* it will be seen that there is a small quantity of steam in the cylinder acting upon the indicator. As the piston advances beyond the point *f*, this steam is compressed, and, by Mariotte's law, when the volume is reduced one-half, the pressure is doubled; and if the volume is reduced one-half again, the pressure is again doubled. The gathering of the steam into a heap at the end of the cylinder, and its being compressed by the advancing piston, are reflected by the indicator, which shows what compression there is. If there were no compression whatever, the piston would have no help in turning the centre. Compression acts as a cushion on which the piston changes the direction of its motion, and it prevents the change being sensibly felt in the movements of the engine.

From *f*, then, the pressure is first raised in consequence of a small quantity of steam being compressed, and the pressure is augmented before the piston reaches the end of the stroke by the pre-admission of steam from the valve-chest, when the pencil of the indicator at once rises to *b*. The admission of the steam to the cylinder before the piston has finished the stroke is due to the lead of the valve. Too much lead causes too much counter-pressure, and too little lead gives rise to unsteady motion of the piston when turning the centre.

We have traced the formation of the diagram through one revolution, and have noted the point of admission, *b*, the point of expansion, *c*, the point of release, *d*, the eduction point, *e*, and the point where compression commences, *f*.

A pair of indicator diagrams, taken from both ends

of the steam-cylinder of a condensing engine, is illustrated by Fig. 29. There the form of the diagram is less sharply defined than in Fig. 26, which represents a diagram taken at a very low speed. The annexed diagrams were taken at the regular working-speed of the engine. The treatment of the movements of the

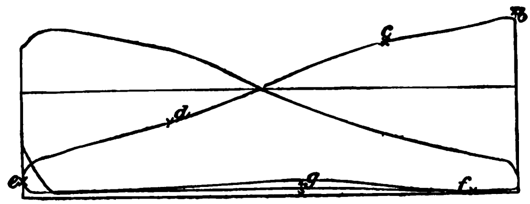


Fig. 29.—Indicator diagrams.

steam may be traced as follows for the right-hand figure:—

b, Point of admission.
bc, Period of ditto.
c, Point of expansion.
cd, Period of ditto.
d, Point of release.
de, Period of ditto.
f, Point of compression.
fb, Period of ditto.
g, Back-pressure.

Defects as pointed out by the Indicator.—If, instead of a nice sharp corner *b*, Fig. 29, we get one slanting to the left, making a round large corner towards *c*, it shows that the valve is without lead, and that the excentric requires to be shifted a little more in advance of the crank, or it may be that the valve-spindle is too long. If the lead-corner *b* is too full, the valve has too much lead, and compression will commence early, and the excentric requires to be shifted towards the crank or backed. If the admission period slopes too much towards the expansion corner *c*, instead of showing a regular maintenance of pressure from *b* to *c*, it shows

that the steam is wire-drawn, that is, that the steam is prevented, either by the regulator or by the valve, from freely entering the cylinder, and that the pressure is reduced between *b* and *c* instead of being constant. This decline may be caused by the steam-ports not being properly proportioned, so as to admit sufficient steam through them in time to follow up the piston with a *full* pressure, and effect a full steam-line, or it may be caused by the steam being condensed in the cylinder, or by water primed over with the steam. It must be understood, however, that the maximum pressure in the cylinder is not absolutely maintained along the whole of the admission-line with perfect regularity, as the reduction of pressure and the absence of sharp corners at the expansion-point and the release-point is partially due to speed, and partially to the valve closing the ports gradually to the steam, and not suddenly cutting off or suddenly releasing it.

The maximum opening of the port is attained midway between the admission-point and the point of cut-off; and it is here that the valve begins to close, and it may be stated that at all ordinary speeds the steam really begins to expand before it is actually cut-off. That it is so, is demonstrated by the declining line *b c* upon the diagram, Fig. 29. After the steam is actually cut off, it is no longer subject to any change, with proper working valves, except that which is fixed by the law of expansion, and the line from *c* to *d* should be nearly hyperbolic in its character—that is to say, the curve should follow Boyle's law. But there are many causes operating within the cylinder to prevent the steam expanding precisely according to that law. If the cylinder is colder than the steam, then condensation

plays a part. If the steam is accompanied with water, or if water is already in the cylinder, the temperature of the steam will rapidly fall. It is in the interval between *c* and *d*—the expansion period—where we must look for signs of a valve leaking. By referring to Fig. 30, it will be seen that the expansion-curve is convex at *b* instead of being concave, which is caused by

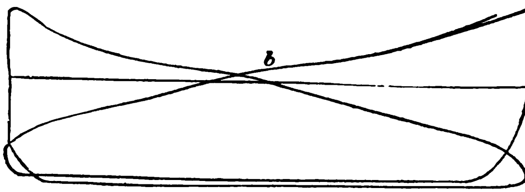


Fig. 30.—Indicator diagram showing the effect of leakage.

the valve "blowing," and admitting steam to the cylinder, when it was supposed to have been cut clean off. The form of the expansion-curve is modified by the extra pressure thus caused disturbing the indicator, and raising the pressure of the steam in the cylinder when the pressure should have been more regularly decreasing.

The expansion line and the exhaust line run into one apparent curve, for at working speeds the whole of the steam does not immediately leave the cylinder when the exhaust is opened, and the portion lingering behind regularly expands to the end of the stroke. That steam produces a useful effect on the piston after the exhaust is open, is seen in the indicator diagram, of which the area is augmented by the exhaust-pressure in the later portion of the diagram. If the eduction corner, Fig. 29, is rounded too much, and the back-pressure

line remains too far from the atmospheric line with excessive and early cushioning at *f*, it is a sign that the valve, having too much inside lap, cannot clear the cylinder of steam before the port is closed. When engines suffer from this defect, they are said to be "wrapped" up, and a considerable proportion of power may be lost by excessive compression. If the exhaust-line runs up at the point of compression *f*, and attains a considerable height, forming a large corner before the steam is admitted, it shows that the valve requires more lead, in order to admit sufficient steam to the piston to keep up the working speed and pressure at the turn of the stroke. If the opening of the port for the admission of steam is late, the admission-corner is rounded off as already stated. So we have gone round the diagram.

When a diagram exhibits defects, the first thing is to observe whether the defects are shown all round the diagram. If they are, they may be rectified by shifting the excentric. If all the movements are late, the excentric must be moved forward; and if they are too early, it must be shifted backward. But if the defect is only local, and confined to one edge of the valve, then the remedy is to shorten or lengthen the valve-rod. Suppose the slide was producing a good diagram, and that for the sake of experiment the excentric was advanced, all the points of distribution would be affected, of course. The admission would be earlier, the cut-off earlier, the exhaust earlier, and the compression earlier. If we obtained in practice a diagram showing that all these points took place too early, the backing of the excentric would effect the required alteration. Again, if the valve be right, and the excentric be then

backed, all the points—admission, cut-off, exhaust, and compression—would be affected, and the steam would be late everywhere. The piston would reverse its course before steam was admitted, the expansion would not take place until the piston was well down the cylinder, and the exhaust would take place when the piston was about to change its course again; and this last defect would be the cause of much back-pressure on the piston.

Causes affecting the edges of the valve.—Suppose the slide of an engine working all right and that the slide-rod were to be shortened; the effect would be that the steam would enter the cylinder on the top stroke earlier, but the cut-off and the exhaust would be later. For the bottom stroke, of course, the very opposite effects would occur. The steam would be *late* in entering the cylinder; it would be cut-off and exhausted *earlier*. If the valve-rod were lengthened, that which happened to the top stroke with a shortened valve-rod would now occur on the bottom stroke, and what occurred on the bottom would happen on the top. For instance: in vertical engines it is necessary to give more steam on the bottom than what is given to the top, to counteract the weight of the piston and the connecting-rod and to assist in making the up-stroke.

Figure 31 is a diagram taken from a vertical engine, and it shows that the engine received more steam on the top than on the bottom. This engine, to all appearance, worked well, though it laboured heavily when making the downward stroke. To any one not experienced in detecting defects, the engine seemed perfection, but a slight increase of steam admitted at the bottom made an unlooked-for improvement. The

engine turned the dead centre with ease, and ran freely at high speed with less thumping and consuming less fuel.

Here was a case which affected the edge of the

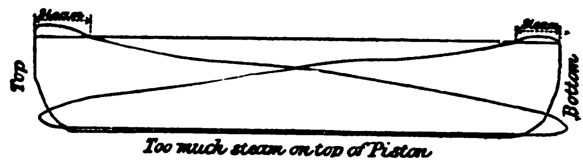


Fig. 31.—Indicator diagram from a vertical steam-engine.

valve. How was the improvement to be made? What did the valve require? It required to be raised, and that was accomplished by inserting a $\frac{1}{16}$-inch liner between the butt-end of the excentric-rod and the excentric-hoop.

This card, Fig. 32, was taken after the alteration of lifting the valve $\frac{1}{16}$-inch was done. It will be seen from this example that, if the engine had happened to

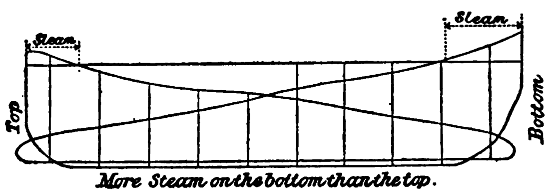


Fig. 32.—Indicator diagram from a vertical cylinder, after the valve was re-set.

have too much steam on the bottom, the necessary alteration could have been effected by taking out a liner or shortening the rod.

To work out Diagrams.—In compound condensing-

engines the steam is either exhausted directly from one cylinder into the other, or it is exhausted into an intermediate receiver, whence it is admitted into the second cylinder. The second plan is followed when the high-pressure and low-pressure cylinders work through their connecting-rods on cranks at right angles to each other; because, as is evident, when one piston is at the end of the stroke the other piston is at about half way, and the receiver is required for holding the exhaust-steam from the high-pressure cylinder until the low-pressure piston arrives at the end of the stroke, and is in readiness to receive it. After the steam has worked the low-pressure piston to the end of the stroke, it is then exhausted into the condenser. Such is the arrangement of the engines from which the cards were taken which we are about to examine.

The double diagram, Fig. 33, taken from the top and the bottom of the cylinder, is divided into ten equal parts; there are nine whole parts, and the two smaller ones at each end are equal to one whole, making ten equal parts.

The scale, said to be $\frac{1}{32}$-inch, represents 1 lb. pressure per square inch of steam on the piston for each $\frac{1}{32}$-inch. For so many $\frac{1}{32}$-inches as are contained in the ordinates to the atmospheric-line reaching between the steam-line and the exhaust-line there are as many pounds of pressure per square inch upon the piston.

Taking the diagram from the bottom of the cylinder, ordinate No. 1 is found, by measurement with a rule, to contain 44 thirty-seconds of an inch, and 44 lbs. is set down beside it. At No. 2 there are 42 thirtv-seconds of an inch, and so on to the

tenth ordinate. Summing up the ten entries of pressure there is a sum of 230·5 lbs. This divided by 10 gives 23·05 lbs., which is the mean-pressure of the steam for the whole of the bottom stroke.

The top side is calculated in the same way, and gives 22·05 lbs. for the mean-pressure. The sum of 23·05 lbs. and 22·05 lbs. = 45·10 lbs., and this divided by 2 gives 22·55 lbs. mean-pressure for one double stroke.

The diagram, Fig. 34, is calculated in the same way

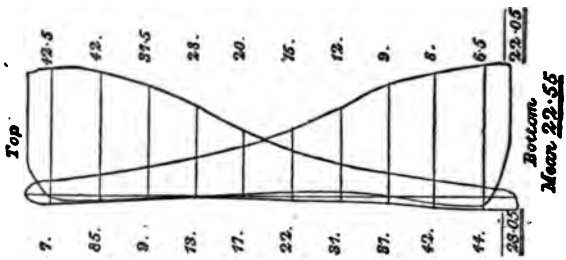


Fig. 33.—Indicator diagrams—measurement of power.

Diameter of cylinder, 44½ inches. Stroke, 45 inches. Scale, $\frac{1}{32}$. Revolutions, 45 per minute. Steam cut off, 15 inches travel of piston. Steam pressure, 45 lbs. per square inch. Indicated horse-power, 354·66.

as the one just explained, but when dealing with a low-pressure diagram there are several points to be noticed. The diagram made by the indicator-pencil is nearly all below the atmospheric-line, as the steam in the low-pressure cylinder was acting on the piston against a vacuum formed on the other side of it, and therefore it was doing useful work, instead of having to overcome atmospheric resistance, which had been removed by the condenser and air-pump. The power exerted by

the steam upon the piston is thus made available for working the machinery. In the diagram under consideration, the steam was admitted to the cylinder just a little above atmospheric-pressure, but acting upon a piston and in a cylinder from which the atmosphere had been withdrawn, we see from the diagram the steam expanded to 10 lbs. below the atmospheric-line. This additional work was obtained by condensing the steam and pumping the air out of the cylinder, so that the piston was free to descend when urged by low-pressure steam.

The total number of pounds pressure = 12·90 lbs. for the top and bottom stroke, which divided by 2 = 6·45 lbs., for the mean-pressure on the piston throughout one double stroke, or for one revolution of the engine.

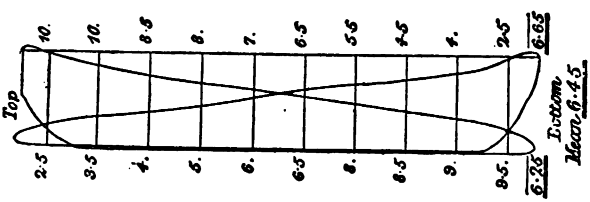


Fig. 34.—Indicator diagrams—measurement of power.

Diameter of cylinder, 79 inches. Stroke, 45 inches. Scale, $\frac{1}{12}$. Revolutions, 45 per minute. Pressure in receiver, $1\frac{1}{2}$ lb. per square inch. Indicated horse-power, $323\frac{3}{8}$.

To work out the Indicator Horse-power.—The measure of a horse-power is a working force that will raise 33,000 lbs. one foot high in *one minute*, or it may be defined as 33,000 *foot*-pounds in one minute. Indicated horse-power is ascertained from diagrams taken with the indicator from the top and the bottom of the

cylinder of the engine when at work. The mean or average pressure during the stroke having been obtained in the way we have explained, the calculation is generally made by squaring the diameter of the cylinder, and multiplying the product by ·7854, which gives the area of the piston, on which the pressure of the steam is exerted, then multiplying by the mean or average pressure per square inch throughout the stroke, then by the stroke, then by the number of revolutions made by the engine per minute. The product expresses the total work done in one minute. This total is divided by 33,000 to find how many times 33,000 lbs. have been lifted one foot high in the minute. The quotient is the actual indicator horse-power.

Example from the indicator card we have examined, worked out, at the end of this work.

Nominal Horse-power is generally calculated from the area of the piston as a datum, without any reference to the speed of the piston or to the pressure. It may be judged that the term may have very various significance. There is no fixed area for horse-power. The term is simply a commercial expression.

Or, if we find the common multiplier of any particular engine, or number of engines, which, so long as the diameter of the cylinder and speed of the piston remain the same, the common multiplier will answer on all future occasions.

To find this common multiplier, multiply the area of the piston in inches, by the speed of the piston in feet per minute, and divide the product by 33000. The quotient equals the common multiplier, or the number of horse-power that each pound of effective force on the piston will drive. Then multiply the

effective mean pressure, as found by diagram, by the common multiplier; the quotient is the indicated horse-power of the engine. Thus, Fig. 33—

```
               1537·8622 area of cylinder
                   337·5 speed of piston in feet per minute
               ---------
                76993110
              107650354
              46135866
             46135866
             -----------
      33000)519029·49250(15·7281
            33000
            -----
            189029
            165000
            ------
             240294
             231000
             ------
               92949
               66000
               -----
               269495
               264000
               ------
                 54950
                 33000
                 -----
                 21750
                 =====
     15·7281
        22·55 mean effective pressure
     -------
       786405
      786405
     314562
    314562
    ----------
    354·668655          Ans. 354·67 I.H.P.
    ==========
```

The consumption of coals per indicator horse-power per hour is found by dividing the number of pounds of coal consumed by the product of the indicated horse-power and the time in hours. The quotient is the quantity consumed per horse-power per hour.

Suppose diagram Fig. 33 represents an engine using 34 tons per week of 58 hours, then the coal consumed per horse per hour is 3·7 lbs., or, say, 3½ per horse. Thus—

2240 × 34 = 76160 lbs. of coal per week
35466 × 58 = 20670 divisor

Then—

```
20670)76160(3·68 lbs. per horse-power
      62010
      ------
      141500
      124020
      ------
       174800
       165360
       ------
         9440
```

CHAPTER XVII.

ARITHMETICAL CALCULATIONS FOR ENGINEMEN.

SIGNS USED IN CALCULATION.

$=$	signifies	Equality	as 3 added to 2	$= 5$
$+$	„	Addition	„ $4 + 2$	$= 6$
$-$	„	Subtraction	„ $7 - 2$	$= 5$
$\times$	„	Multiplication	„ 6×2	$= 12$
$\div$	„	Division	„ $12 \div 2$	$= 6$
$: :: :$	„	Proportion	„ 2 is to 3 as 4 is to 6	
$\sqrt{}$	„	Square root	„ $\sqrt{16}$	$= 4$
$\sqrt[3]{}$	„	Cube root	„ $\sqrt[3]{64}$	$= 4$
3^2	„	3 is to be squared	„ 3^2	$= 9$
3^3	„	3 is to be cubed	„ 3^3	$= 27$
$\overline{2+5} \times 4$	„	that 2 and 5 = 7, and four times 7		$= 28$

$\sqrt{5^2 - 3^2} = 4$. This reads, 3 squared taken from 5 squared, and the square root extracted . $= 4$

$\sqrt[3]{\dfrac{10 \times 6}{15}} = 1{\cdot}587$, reads, 10 multiplied by 6 and divided by 15; the cube root of the quotient . . $= 1{\cdot}587$

SIMPLE PROPORTION.

When we have three numbers given, this rule teaches how to find a fourth number, which may have the same proportion to the third number that the second has to the first.

Thus, if the three given numbers be 3, 9, 4, it is required to find a fourth number which will have the same proportion to 4 that 9 has to 3; now the 9 is 3

times the 3, therefore the required number must be 3 times the 4, that is 12.

To express proportions the numbers are put down thus 3 : 9 : : 4 : 12, and reads thus 3 is to 9 as 4 is to 12.

RULE, WITH EXAMPLE.—Place them thus 3 : 9 : : 4 and multiply the second and third numbers together, and divide by the first.

$$\begin{array}{r} 4 \\ \hline 3)\ 36 \\ \hline 12 \text{ Ans.} \end{array}$$

To 3. 6. 12	find a	fourth proportional.	Answer, 24.
„ 6. 12. 4	„	„	„ 8.
„ 10. 150. 68	„	„	„ 1020.
„ 68. 1020. 10	„	„	„ 150.

If 4 lbs. of tallow cost 20 pence, what will 16 lbs. cost?

RULE, WITH EXAMPLE.—In this question there are two things mentioned, tallow and money; the answer required is the price, money,

Put down the money—20 pence—for the third term. This is always so, that is, the third term is of the same kind as the answer required, and this is worth remembering. If the *answer* is to be greater than the third term the greater is placed second, and if it is to be less it is placed first, and the less, of course, second. The question before us requires an answer greater than the third term, and is worked out thus—

$$\begin{array}{l} 4 \text{ lbs.} : 16 \text{ lbs.} : : 20 \text{ pence} \\ \qquad\qquad 20 \\ \hline 4)\ 320 \\ \hline \qquad 80 \text{ pence} = 6s.\ 8d. \quad \text{Ans.} \end{array}$$

If 6s. 8d. will purchase 16 lbs. of tallow, how many

pounds will 1s. 8d. buy? Here the answer is to be less than the third term, and it is pounds of tallow and not money; therefore observe,

Pence.		Pence.		lbs.
80	:	20	: :	16

$$\begin{array}{r} 16 \\ \hline 120 \\ 20 \\ \hline 80)\ 320 \\ \hline 4 \text{ lbs. Ans.} \end{array}$$

DECIMALS.

By decimals are meant tenths. Decimal arithmetic is the simplest possible method of working calculations.

It is worthy of special attention that, in decimals, the dot performs a very important part: separating integers from ciphers, or the fractional parts from a whole. Decimals, contrary to vulgar fractions, are written in one line like integers; and they are, in all respects, worked out in a plane-sailing way.

Decimal fractions are written thus . . . ·25 : ·5 : ·75 :
Their equivalents in vulgar fractions are written . $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$

The value of a decimal is altered by placing ciphers to the left, but not by placing ciphers to the right.

Thus ·05 $= \frac{5}{100}$; and, by placing a cipher to the left, the decimal becomes ·005, or $\frac{5}{1000}$, which is ten times less than $\frac{5}{100}$.

ADDITION OF DECIMALS.

Add 4·15; ·002; ·3:—

$$\begin{array}{r} 4{\cdot}15 \\ {\cdot}002 \\ {\cdot}3 \\ \hline 4{\cdot}452 \end{array}$$

Observe the position of the dot.

SUBTRACTION OF DECIMALS.

RULE.—If the number of decimal places be not the same in all the fractions, annex so many ciphers to the right hand as will render it so. We do not alter the value of the fractions so supplied, but they are reduced to the same denominator.

Subtract 106·125 from 125·5.

```
125·500
106·125
-------
 19·375    Ans. 19⅜.
```

MULTIPLICATION OF DECIMALS.

RULE.—Arrange the numbers as if they were integers.

Multiply 148·74 by 2·67.

```
148·74 } Observe 4 decimal
  2·67 }  figures used.
------
104118
 89244
29748
--------
397·1358 (Four Decimals cut off.)
```

NOTE.—Count the number of decimals in both the multiplicand and the multiplier, and point off as many figures from the right hand of the product.

Multiply ·02 by ·045.

```
   ·02
  ·045
------
·00090
```

In counting the number of decimals in the multiplicand and multiplier to point off in the product, if there are not sufficient figures in the product, place cipher to the left, and prefix the dot as above

DIVISION OF DECIMALS.

RULE.—Divide as in whole numbers, and mark off in the quotient as many decimal places as the dividend has more than the divisor.

Divide 72·125 by 6·25.

```
Dvsr. Dividnd. Quot.
6·25)72·1250̂(11·54
     62 5
     ----
      9 62
      6 25
      ----
      3 375
      3 125
      -----
        2500
        2500
        ----
        ....
```

The cipher in the dividend is brought in and shown above as making the number of decimals in the dividend equal to the number in the divisor and quotient together.

REDUCTION.

To reduce a Vulgar Fraction to a Decimal.

RULE.—Divide the numerator by the denominator, annexing as many ciphers to the numerator as may be necessary. Point off as many decimal places in the quotient as there are ciphers annexed to the numerator.

Reduce $\frac{1}{4}$ to a decimal.

```
4)10̂0̂       Observe 2 ciphers added.
 ---
 ·25 Ans.    „     2 decimals cut off.
```

Reduce $\frac{3}{4}$ to a decimal.

$$4)3\hat{0}\hat{0}$$
$$\overline{\cdot 75}\ \text{Ans.}$$

Reduce $\frac{7}{8}$ to a decimal.

$$8)7\hat{0}\hat{0}\hat{0}$$
$$\overline{\cdot 875}$$

The annexed table, of decimal equivalents of the fractional parts of an inch, is calculated as above.

Vulgar Fraction.	Decimal Equivalent.	Vulgar Fraction.	Decimal Equivalent
$\frac{1}{32}$	·03125	$\frac{1}{2}\ \frac{1}{32}$	·53125
$\frac{1}{16}$	·0625	$\frac{1}{2}\ \frac{1}{16}$	·5625
$\frac{3}{32}$	·09375	$\frac{1}{2}\ \frac{3}{32}$	·59375
$\frac{1}{8}$	·125	$\frac{5}{8}$	·625
$\frac{1}{8}\ \frac{1}{32}$	·15625	$\frac{5}{8}\ \frac{1}{32}$	·65625
$\frac{3}{16}$	·1875	$\frac{5}{8}\ \frac{1}{16}$	·6875
$\frac{1}{8}\ \frac{3}{32}$	·21875	$\frac{5}{8}\ \frac{3}{32}$	·71875
$\frac{1}{4}$	·25	$\frac{3}{4}$	·75
$\frac{1}{4}\ \frac{1}{32}$	·28125	$\frac{3}{4}\ \frac{1}{32}$	·7812
$\frac{1}{4}\ \frac{1}{16}$	·3125	$\frac{3}{4}\ \frac{1}{16}$	·8125
$\frac{1}{4}\ \frac{3}{32}$	·34375	$\frac{3}{4}\ \frac{3}{32}$	·84375
$\frac{3}{8}$	·375	$\frac{7}{8}$	·875
$\frac{3}{8}\ \frac{1}{32}$	·40625	$\frac{7}{8}\ \frac{1}{32}$	·90625
$\frac{3}{8}\ \frac{1}{16}$	·4375	$\frac{7}{8}\ \frac{1}{16}$	·9375
$\frac{3}{8}\ \frac{3}{32}$	·46875	$\frac{7}{8}\ \frac{3}{32}$	·96875*
$\frac{1}{2}$	·5	1	1·000

To reduce Money, &c.

RULE.—Divide by as many of the lower denomination as make one of the higher, annexing ciphers at will. If there be several denominations, proceed in the same manner with each, beginning with the lowest denominator.

* Reads—Decimal nine six eight seven five.

Reduce 12s. $8\frac{1}{4}$d. to the decimal of a pound sterling.

$$
\begin{array}{lr}
\text{(4 farthings = 1 penny} & 4)1\hat{0}\hat{0} \\
\text{(12 pence = 1 shilling} & 12)8{\cdot}25\hat{0}\hat{0} \\
\text{(20 shillings = £1} & 20)12{\cdot}6875\hat{0} \\
 & \underline{\underline{{\cdot}634375}}
\end{array}
$$

$\cdot634375$ = decimal value of 12s. $8\frac{1}{4}$d.

To re-value this decimal, multiply it by the various fractional denominations of the whole number, cutting off from the right hand of each product, for decimals, a number of figures equal to the number of decimals given, then multiply the remainder by the next lower denomination, and proceed until the lowest is reached.

·634375	6 decimals.
20	
12·687500	6 decimals cut off.
12	
8·250000	" "
4	
1·000000	" "
Ans.	12s. $8\frac{1}{4}$d.

To find the Value of a Decimal.

Rule.—Multiply the decimal by the number of the next lower denomination which is equal to one of its present denomination. Cut off as many places as there are places in the multiplicand.

Find the value of ·75 foot.

$$
\begin{array}{r}
{\cdot}75 \\
12 \\
\hline
\underline{\underline{9{\cdot}00}}
\end{array}
$$

Ans. 9 inches.

Find the value of ·3875 of a £.

$$\begin{array}{r} \cdot 3875 \\ 20 \\ \hline 7\cdot 7500 \\ 12 \\ \hline 9\cdot 0000 \\ \hline\hline \end{array} \quad \text{Ans. 7s. 9d.}$$

Find the value of ·375 ton.

$$\begin{array}{r} \cdot 375 \\ 20 \\ \hline 7\cdot 500 \\ 4 \\ \hline 2\cdot 000 \\ \hline\hline \end{array} \quad \text{Ans. 7 cwt. 2 qrs.}$$

INVOLUTION.

When a number is multiplied by itself, the product is called a power, and the number multiplied is called the root.

Thus $2 \times 2 = 4$. Here 4 is the square or second power of the root 2. Again, $2 \times 2 \times 2 = 8$. Here 8 is the third power of 2.

EVOLUTION.

Evolution is the method of finding the root of a number.

To extract the square root of any given number is to find a number which, when multiplied by itself, will produce the given number.

Extract the square root of 55225.

RULE, WITH EXAMPLE.—Divide the given number into periods, that is, set a dot over the unit and right-hand figure, and then over every alternate figure towards the left. Find the square root (2) of the first

period (5), and place it in the quotient. Subtract the square of it (4) from the first period (5), and to the remainder annex the next period (52) for a dividend. Double 2, the root already found for a divisor, and place it (4) to the left of the dividend, looking upon it as 40 and not 4. After finding that this divisor (40) will go 3 times in the dividend (152), place the figure representing the number of times in the quotient, and also in the divisor, making the latter 43; then multiply the 43 by 3, and subtract the product. Bring down another period (25).

In forming the second divisor, 465, double the last figure (3) in the first divisor, and look upon it as 460. After finding that this divisor (460) will go 5 times in the dividend, place the 5 in the quotient and divisor, making the latter 465; then multiply the 465 by the 5 just placed in the quotient, and subtract the product, which leaves nothing; 235 being the answer.

```
       5̇52̇25̇(235
       4
       ---
    43)152
       129
       ----
  465) 2325
       2325
       ====
```

What is the square root of 177241?

```
      177241(421
      16
      ---
  82) 172
      164
      ----
 841)  841
       841
      ---
      ...
      ===
```

EXTRACTION OF THE THIRD OR CUBE ROOT.

To extract the cube root of any given number is to find a number which, when multiplied twice by itself, will produce the given number.

RULE, AND EXAMPLE.—Make a dot over every third figure, beginning at the unit or right-hand figure point to the left with whole numbers and towards the right in decimals.

What is the cube root of $88\dot{4}73\dot{6}$? Place the root (9) of the first period (884) in the quotient, on the right, and its cube (729) under the first period (884). Subtract, and to the remainder (155) bring down the next period of three figures (736). Multiply the square of the quotient ($9 \times 9 = 81$) by 300 for a divisor. Find how often it is contained in the dividend, and put the number (6) in the quotient. Multiply the divisor (24300) by this number (6). Add to the product the amount of all the figures in the quotient (9), multiplied by 30 —except the last (6)—and the product by the square of the last.

To these figures add the cube of the last figure in the quotient, and subtract the sum of the whole from the dividend; thus—

$\sqrt[3]{88\dot{4}73\dot{6}}$(96 Ans.

729

$9 \times 9 \times 300 = 24300$)155736*

$\cancel{145800}$

145800 = divisor $\times$ 6

9720 = $9 \times 30 \times 6^2$

216 cube of 6

155736* see figs. in dividend above.

Another way:—

What is the cube root of 10648?

$$\sqrt[3]{10648}(22$$

$$8$$

$$2 \times 2 \times 3 = 12)264\cancel{8}$$

Here, after squaring the root of the first period, we multiply it by 3 = 12, and, rejecting the units and tens, we find the divisor is contained twice in the dividend, which is put in the quotient, making 22, the cube root of 10648.

Proof—

```
   22
   22
   --
   44
  44
  ---
  484 square of 22
   22
  ---
  968
 968
-----
10648 cube of 22
```

MENSURATION, ETC.

The kinds of measurement are three, viz., Lineal, Superficial, and Solid.

Lineal measure respects or refers to length only, as twelve inches. *Superficial* measure refers to length and breadth, as twelve inches in length, and twelve inches in breadth = 144 square inches, which is equal to 1 square foot. *Solid* measure refers to length, breadth, and depth, as twelve inches in length, twelve inches in breadth, and twelve inches in depth = 12 in. × 12 in. × 12 in. = 1728 cubic inches = 1 cubic foot.

Lineal Measure.—A connecting-rod of an engine is, say, 6 feet 6 inches from the centre of the big end to the centre of the little end; from the centre of the big end to the outside of the strap the length is 6 inches; from

the centre of the little end to the outside of the strap the length is 4½ inches. Required the total length.

6 ft. 6 in. + 6 in. + 4½ in. = 7 ft. 4½ in.

Superficial Measure.—A slab of iron is 12 feet 6 inches long and 1 foot 3 inches broad. What is the superficial measurement or area of the slab?

This can be found in four several ways, viz., by Decimals, by Whole Numbers, by Cross-Multiplication, and by Practice. Thus—

(1) Decimals.

```
              12·5
               1·25
            ------
               625
              250
             125
            ------
Feet        15,625
                12
            ------
Inches       7,500
                 4
            ------
Quarters     2,000
            ======
```

(2) Whole Numbers.

```
      150 inches
       15 inches
      ---
      750
      150
      ----
144)2250(15 feet
    144
    ---
     810
     720
     ---
      90
      12
     ----
144)1080(7 inches
    1008
    ----
      72
       4
     ---
144)288(2 quarters
    288
    ---
    ...
    ===
```

(3) By Cross-Multiplication.

```
12 ·6
 1 ·3
---------
12 ·6
 3 ·1 ·6
---------
15 ·7 ·6
=========
```

(4) By Practice.

```
       12 ·6
        1 ·3
       -----
       12 ·6
3=¼     3 ·1½
       -----
       15 ·7½
       =====
```

Although the fourth method is the shortest, the first is much more generally practical, under the many changes which crop up in dealing with fractional parts; and in order to initiate enginemen into the practice of using them, we have given examples how to work them.

Solid Measure.—A block of iron is 12 inches long, 12 inches broad, and 12 inches deep. How many cubic inches does it contain?

$$
\begin{array}{r l}
12 & \\
12 & \\
\hline
144 & \\
12 & \\
\hline
\underline{1728} & \text{cubic inches.}
\end{array}
$$

A sheet of iron is 120 inches long, and at one end it is 34 inches wide, and at the other end 10 inches. What is the superficial measurement?

$$
\begin{array}{r r l}
 & \text{Inches.} & \\
 & 34 & \\
 & 10 & \\
\hline
 & \tfrac{1}{2})44 & \\
\hline
\text{1 foot 10 inches} = \text{inches} & \underline{\underline{22}} & \text{The medium between the least and greatest length.}
\end{array}
$$

$$
\begin{array}{l r r}
 & \text{ft.} & \text{in.} \\
 & 10 & 0 \\
 & 1 & 10 \\
\hline
 & 10 & 0 \\
 & 8 & 4 \\
\hline
\text{Ans.} & \underline{\underline{18}} & \underline{\underline{4}}
\end{array}
$$

Solid Measure.—A block of iron is 12 inches long, 12 inches broad, and 12 inches deep. How many cubic inches does it contain?

$$
\begin{array}{r}
12 \\
12 \\
\hline
144 \\
12 \\
\hline
1728
\end{array}
\text{ cubic inches} = 1 \text{ cubic foot.}
$$

A boiler-plate is 6 feet 9 inches long, 4 feet 6 inches wide, and $\frac{3}{8}$ths of an inch thick. How many cubic inches does it contain?

$$
\begin{array}{lr l}
\text{Length} = & 81 & \text{inches} \\
\text{Width} = & 54 & \text{,,} \\
\hline
 & 324 & \\
 & 405 & \\
\hline
 & 4374 & \times \frac{3}{8} \\
 & 3 & \\
\hline
 & 8)13122 & \\
\hline
 & 1640 \cdot 25 &
\end{array}
$$

Ans. $1640\frac{1}{4}$ cubic inches.

To calculate the indicated horse-power from an indicator diagram, Fig. 33.

$$
\frac{d^2 \times \cdot 7854 \times 22 \cdot 55 \text{ lbs.} \times 7 \cdot 5 \times 45}{33000}
$$

High-pressure cylinder

$$
\begin{array}{r l}
44 \cdot 25 & \text{diameter of cylinder in inches} \\
44 \cdot 25 & \\
\hline
22125 & \\
8850 & \\
17700 & \\
17700 & \\
\hline
1958 \cdot 0625 & \text{square inches} \\
\cdot 7854 & \\
\hline
78322500 & \\
97903125 & \\
156644940 & \\
137064375 & \\
\hline
1537 \cdot 86222750 & \text{area of piston}
\end{array}
$$

1537·86222750 area of piston
22·55 mean-pressure obtained from indicator-card

768931113750
768931113750
307572445500
307572445500

34678·7932301250 total pressure
7·5 twice the stroke, 3 ft. 9 in. × 2 = 7 ft. 6 in.; or by decimals, 7·5 ft.

1733939661506250
2427515526108750

260090·94922593750 work done in one stroke in foot pounds
45 revolutions per minute

$\left.\begin{array}{r}1300454746129687\,50\\ 1040363796903750\,00\end{array}\right\}$ work done per minute lbs. lifted per minute

33,000)11704092·71516718750(354·669
99000

180409
165000

154092
132000

220927
198000

229271
198000

312715
297000

15715

Ans. Indicated horse-power, $354\frac{3}{4}$.

It will be observed we first multiply the diameter by the diameter (44·25 × 44·25) using decimal arithmetic, which is the simplest possible method of working calculations where there are fractional parts. The product is multiplied by ·7854 to find the area of the piston, or

the number of square inches on which the steam can act. We then multiply by the mean-pressure of the steam, which we found from the indicator diagram to be 22·55 lbs. per square inch, which gives the total pressure exerted on the face of the piston ($34678\frac{3}{4}$ lbs.). This pressure is exerted throughout the top and the bottom stroke; and therefore it is multiplied by the length of the two strokes in feet (3 ft. 9 in., or by decimals, 3·75 ft. $\times$ 2 = 7·5 ft.), which gives the work done in one revolution, or the pounds lifted one foot high in one revolution; and as these pounds are lifted one foot high *forty-five times* a minute, we multiply by 45 revolutions, and therefore obtain the total number of pounds raised one foot high in one minute. This total divided by 33,000 lbs., which is the number of pounds a horse is supposed to lift one foot high in one minute, shows how many horses it would take to do the same work in the same time. What is understood is this: steam, having a pressure of $22\frac{1}{2}$ lbs. per square inch, moving a piston, whose area is 1,537 square inches, at the rate of 337 feet per minute, is exerting a force capable of resisting the joint efforts of 354 horses, or the power is equal to 354 indicator horse-power.

To obtain the indicated horse-power from a diagram, Fig. 34.

$$\frac{d^2 \times \cdot7854 \times 6\cdot45 \text{ lbs.} \times \text{twice the stroke} \times 45}{33000}$$

Low-pressure cylinder

$$\begin{array}{rl} 79 & \text{diameter of cylinder in inches} \\ 79 & \\ \hline 711 & \\ 553 & \\ \hline 6241 & \text{circular inches} \end{array}$$

```
             6241 circular inches
            ·7854
            -----
            24964
           31205
          49928
         43687
        ---------
        4901·6814 area of piston in square inches
             6·45 mean-pressure obtained from indicator
       ----------      diagram
       245084070
      196067256
     294100884
     ------------
     31615·845030 total pressure
              7·5 twice the stroke, 3·75 × 2 = 7·5
     ------------
     158079225155
   221310915210
   --------------
   237118·8377255 work done in one stroke, foot-lbs.
               45 revolutions per minute
   --------------
   11855941886275
   9484753509020
   --------------
33000)10670347·6976475(323·343
      99000
      -----
       77034
       66000
       ------
       110347
        99000
        ------
        113476
         99000
         ------
         144769
         132000
          ------
          127697
           99000
           -----
           28697
```

Ans. Indicated horse-power, 323⅜ nearly.

Another way. By using the constant logarithm from

a table, the number of figures used is much reduced, and the result is the same.

Taking the same diagrams and particulars as before. The first point is to find at what speed per minute the engine is running.

```
  3·75 feet
    45 revolutions
  ----
  1875
 1500
 -----
 16875
     2
 -----
337·50 feet per minute
```

Then—

By constant log. × feet per minute × by mean-pressure.

High-pressure cylinder.	Low-pressure cylinder.
·046601 log.	·148535 log.
337·5 speed	337·5
233005	742675
326207	1039745
139803	445605
139803	445605
15·7278375	50·1305625
22·55 mean-pressure	6·45
786391875	2506528125
786391875	2005222500
314556750	3007833750
314556750	323·342128125
354·662735625	

Indicated horse-power combined—

```
High-pressure  354·662
Low-pressure   323·342
               -------
               678·004
```

Required the average effective pressure per square inch on the piston of an engine.

RULE.—(*a*) Find the area of the piston by squaring the diameter of the cylinder, and multiplying it by ·7854; multiply by twice the stroke, and by the number of revolutions per minute. (*b*) Multiply the indicator horse-power by 33,000, and divide the product by the product *a*. The quotient gives the answer.

EXAMPLE.—Diameter of cylinder, $44\frac{1}{4}$ inches; length of stroke, 45 inches; revolutions per minute, 45; indicator horse-power, $354\frac{3}{4}$.

```
   354·669
     33000
-----------
1064007000
1064007
-----------
11704077000
===========
```

```
          44·25
          44·55
         ------
          22125
          8850
         17700
        17700
         ------
      1958·0625
          ·7854
      ---------
       78322500
      97903125
     156644940
    137064375
    -----------
  1537·86222750
            7·5
  -------------
   768931113750
  1076503559250
  -------------
11533·996706250
             45
  -------------
 57669983531250
46135986832000
  -------------
519029·851851250
================
```

```
519029·8518)11704077000·000(22·54
            10380597036
            -----------
            13234791640
            10380597036
            -----------
             28541946040
             25951492590
             -----------
              25904536500
              20761194072
              -----------
               5143342428
```

Ans. 22·54 lbs. per square inch of piston.

Required the number of cubic feet of steam consumed per hour by an engine. And also the steam—equivalent as water at a given pressure.

Rule.—Square the diameter of cylinder; multiply by ·7854, by the number of revolutions per minute, by 60, by double the stroke in inches, and by the cut-off, divide by 1728, and by 437, and multiply the product by 62·5.

Example.—Diameter of cylinder, 44¼ inches; length of stroke, 45 inches; revolutions per minute, 45; steam cut-off at one-third of the stroke; pressure of steam, 45 lbs. per square inch.

```
         44·25 = diameter of cylinder
         44·25
         -----
         22125
         8850
       17700
      17700
      ---------
      1958·0625 = diameter squared
          ·7854
      ---------
      78322500
     97903125
   156644940
  137064375
  -------------
  1537·86222750 = area
```

1537.86222750 = area
45 revolutions

7689311113750
615150891000

69204·40023750
60 minutes in hour

4152264·01425000
90 stroke 45 × 2

Cut off = $\frac{1}{3}$)373703761·28250000

1728 inches in a cubic foot } 12 | 124567920·42750000

12 | 10380660·03562500

12 | 865055·00296800

72087·91691400

*437)72088(164·96 cubic feet
437

2838
2622

2168
1748

4200
3933

2670
2622

....

Weight of a cubic foot of water

165
62·5

825
330
990

10·312

Answers:—

Cubic feet of steam = 72,088.
Water evaporated = 10·312 lbs. per hour.

A tank is $8\frac{3}{4}$ feet long and $4\frac{1}{4}$ feet broad. What height must it have to contain 1,210 gallons?

RULE.—Multiply the number of gallons (1,210) the

* The relative volume of steam at this pressure, 45 lbs., compared with water from which it was raised.

T

tank is required to contain, by ·16,* or divide by $6\frac{1}{4}$; the result is the contents in cubic feet. Then multiply the length by the breadth ($8·75 \times 4·25$), and the result is the area of the bottom of the tank. Then divide the contents in cubic feet by the area, and the product is the height in feet and decimals of a foot.

Gallons	Feet
1210	8·75
·16	4·25
7260	4375
1210	1750
	3500
193·60 cubic feet of water.	37·1875 area of tank bottom.

Cubic Feet

37·1875)193·60000(5·206
1859375 12
766250 2·472
743750
2250000
2231250
18750

Ans. 5 ft. $2\frac{1}{2}$ in. nearly.

A tank is 7 feet long and 3 feet 4 inches broad. What height must it have to contain 900 gallons?

Ans. 6 ft. 2 in.

The stroke of an engine is 30 inches; the slide-valve travel is 5 inches; the lap is $1\frac{1}{2}$ inches, and the lead $\frac{1}{16}$ inch. At what distance from the end of the stroke will the piston be when the steam is cut off?

RULE.—Multiply the lap by 2, and add the lead; divide the sum by the travel, square the quotient, and

* 1 gallon of water = ·16 cubic foot.

multiply it by the length of stroke; the product is the distance of piston from the end of stroke when the steam is cut off.

The distance of the piston from end of stroke $= \left(\frac{1{\cdot}5 \times 2 + {\cdot}0625}{5}\right)^2 \times 30.$

$$
\begin{array}{lr}
\text{Lap} = & 1{\cdot}5 \\
 & 2 \\
\hline
 & 3{\cdot}0 \\
\text{Lead} = & {\cdot}0625 \\
\hline
\text{Travel}=5) & 3{\cdot}0625 \\
\hline
 & {\cdot}6125 \\
 & {\cdot}6125 \\
\hline
 & 30625 \\
 & 12250 \\
 & 6125 \\
 & 36750 \\
\hline
 & {\cdot}37515625 \\
\text{Stroke} = & 30 \\
\hline
 & 11{\cdot}25468750 \\
\end{array}
$$

Ans. $11\frac{1}{4}$ in

Required the weight to be placed at end of a safety-valve lever, to give a blowing-off pressure equal to 20 lbs. per square inch; diameter of valve 5 inches, distance from centre of valve to fulcrum 6 inches, and from valve to weight 10 inches; effective weight of the lever, or its actual pressure on the valve, 80 lbs; weight of valve 12 lbs.

RULE.—Square the diameter of the valve, and multiply by ·7854, to find the area, multiply the product by the given pressure; deduct the sum of the weight of the lever and valve; multiply the remainder by the distance from the fulcrum to the valve, and divide the

product by the distance from the fulcrum to the weight. Thus—

$$5^2 \times \cdot7854 \times 20 - 92 \times 6 \div 16 = 112\tfrac{3}{4} \text{ lbs.}$$

```
  5            ·7854
  5               25 square of valve
 ——           ———————
 25            39270
              15708
              ———————
              19·6350
                   20 lbs. pressure required
              ————————
              392·7000
               92       lbs. weight of lever and valve
              ————————
              300·7
                  6 distance from fulcrum to valve
          ( 4 |———————
       16 {   | 1804·2
          |   |———————
          ( 4 | 451·05
              ————————
              112·76  weight required
              ======
               Ans.   112¾ lbs.
```

NOTE.—This is a very simple rule and easy to work.

A packing-ring for a cylinder 48 inches diameter is required. One is found near at hand, but it is 50 inches in diameter; how much must be cut out of it to make it fit the cylinder?

```
Difference of diameter × 3·1416 = inches to cut out
                  Ring  50                   3·1416
              Cylinder  48                        2
                        ——                   ——————
Difference of diameter   2                   6·2832
                        ==                   ======
```

Ans. $6\frac{5}{32}$ in. to be cut out to make it fit.

A packing-ring for a cylinder is 89 inches diameter; before being cut was $91\frac{1}{4}$ inches. How much must be cut out of it to make it fit the cylinder?

Ans. 7·0686.

Required the cubic feet of water a pump will discharge per hour; diameter of plunger 3 inches; stroke 14 inches long, making 25 strokes a minute.

RULE.—Multiply the area of plunger by the length of stroke and revolutions per minute, and divide by 1728.

```
3"             ·7854
3                  9
-             ------
9             7·0686
                  14 stroke
              ------
              282744
              70686
              ------
             989·604 capacity of pump in inches
                  25 revolutions per minute
             -------
            4948020
           1979208
           ---------
           24740·100
                  60 revolutions per hour
            -----------
          12 | 148440·6000
             |------------
1728=     12 |  12370·0500
             |------------
          12 |   1030·8375
             |------------
                   85·9031
                  =========
```

Ans. 86 cubic feet of water.

Weight $=86 \times 62\frac{1}{2}=5375$ lbs.

NOTE.—A cubic foot of water weighs $62\frac{1}{2}$ lbs.

Again. Particulars as in last question; but, suppose the pump at each stroke is $\frac{3}{4}$ths full instead of being full.

```
3              ·7854
3                  9
-             ------
9             7·0686 area of plunger end
```

```
        7·0686 area of plunger end
            14 length of plunger
        ------
        282744
        70686
        ------
       98·9604 total area in length of stroke
            25 stroke
       -------
       4948020
      1979208
      --------
     2474·0100  ⎫
             3  ⎪
     ---------  ⎬ 3/4 full
   4)7422·0300  ⎪
     ---------  ⎪
     1855·5075  ⎭
            60 minutes
        12 | 111330·4500
1728 =  12 |   9277·5375
        12 |    773·1281
                 64·4273
```

Ans. $64\frac{1}{2}$ cubic feet of water

Parts of a 48-inch stroke.

40 inches	$\frac{5}{6}$	6 inches	$\frac{1}{8}$
32 "	$\frac{2}{3}$	4 "	$\frac{1}{12}$
24 "	$\frac{1}{2}$	3 "	$\frac{1}{16}$
16 "	$\frac{1}{3}$	2 "	$\frac{1}{24}$
12 "	$\frac{1}{4}$	1 "	$\frac{1}{48}$
8 "	$\frac{1}{6}$		

The steam is cut off at $\frac{1}{3}$rd of the stroke of 42 inches; what is the distance the piston has travelled?

```
3)42 inches
  --
  14 inches.  Ans.
```

Again. The steam is cut off at $\frac{1}{8}$th of the stroke.

```
8)42 inches
  --
  5¼ inches.  Ans.
```

What is $\frac{5}{6}$ths of the same stroke of piston?

$$\begin{array}{r} 42 \\ 5 \\ \hline 6)210 \\ \hline 35 \text{ inches.} \end{array}$$

If the piston, having a 42-inch stroke, comes to rest at $\frac{1}{12}$th of the stroke, what distance is it from the nearest cover, neglecting the clearance, and the obliquity of the connecting-rod?

$$\begin{array}{r} 12)42 \\ \hline 3\frac{1}{2} \text{ inches.} \end{array}$$

Prove it—

$$\begin{array}{r} 3\frac{1}{2} \\ 12 \\ \hline 42 \end{array}$$

Prove that 35 inches is $\frac{5}{6}$ths of 42 inches

$$\begin{array}{r} 35 \text{ inches} \\ 6 \\ \hline 5)210 \\ \hline 42 \text{ inches. Ans.} \end{array}$$

APPENDIX.

TO TEST THE QUALITY OF IRON.

If the fracture gives long silky fibres, of leaden-grey hue, fibres cohering and twisting together before breaking, the iron may be considered a tough, soft iron.

A medium even grain, mixed with fibres—a good sign.

A short blackish fibre indicates badly refined iron.

A very fine grain denotes a hard steely iron, apt to be cold-short, hard to work with a file. Coarse grain, with brilliant crystallized fracture, yellow or brown spots, denotes a brittle iron, cold-short, working easily; when heated welds easily.

Cracks on the edges of bars, sign of hot-short iron.

Good iron is readily heated, soft under the hammer, throws out but few sparks.

Iron, with heating, if exposed to air, will oxidize; when at white heat, if in contact with coal, will carbonize, or become steely.

To restore burnt iron—give a smart heat, protected from the air, if injured by cold hammering; anneal slowly and moderately, if hard or steely; give one or more smart heats to extract the carbon.

KNOTS.

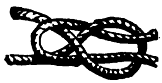


Fig. 35.—A Common Bend.

A Common Bend.—It is formed by passing the end of a rope through the bight of another rope, then round both parts of a rope and down through its own bight.

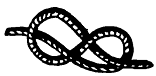


Fig. 36.—Figure of Eight Knot.

Figure of Eight Knot.—Take the end of the rope round the standing part, under its own part and through the lower bight.

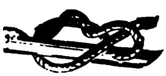


Fig. 37.—Timber Hitch.

Timber Hitch.—It is made by taking the end of a rope round a spar, passing it under and over the standing part, and then passing several turns round its own part.

Fig. 38.—A Fisherman's Bend.

Fisherman's Bend.—With the end of a rope take two turns round, then form a half-hitch round the standing part, and under the turns, and another half-hitch round the standing part.

Fig. 39.—Two Half-hitches.

To make Two Half-hitches.—Pass the end of the rope round the standing part, and bring it up through the bight—this is one half-hitch; two of these, one above the other, constitute two half-hitches.

Fig. 40.—Overhand Knot.

Overhand Knot.—This is made by passing the end of the rope over the standing part and through the bight.

Fig. 41.—Rolling Bend.

Rolling Bend.—It is something similar to a fisherman's bend. It is two round turns round a spar, two half-hitches around the standing part, and the ends stopped back.

To make a Bowline Knot.—Take the end of the rope in your right hand, and the standing part in your left; lay the end over the standing part, then with your left hand turn the bight of the standing part over the end part; then lead the end through the standing part above, and stick it down through the cuckold's neck formed on the standing part, and it will appear as the sketch.

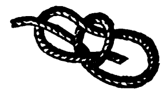


Fig. 42.—A Bowline Knot.

A Reef Knot.—First make an overhanded knot, supposing it to be round a yard; then bring the end being to you over the left hand, and through the bight haul both ends taught. This knot is used chiefly for joining the ends of ropes or lines together.

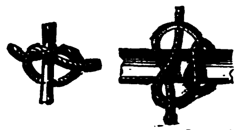


Fig. 43.—Square or Reef Knot.

A Short Splice.—A short splice is made by unlaying the ends of two ropes, or the two ends of one rope, to a sufficient length, then crutch them together as per adjoining sketch; draw them close and push the strands of one under the strands of the other, the same as the eye-splice. This splice is used for block-straps, slings, &c. If the ends are to be served over, they are but once stuck through; if not, they are stuck twice and cross-whipped across the strands, so as to make them more secure. When the ends are to be served, take a few of the underneath yarns, enough to fill up the lay of the rope for worming, then scrape or trim the outside ends, and marl them down ready for serving.

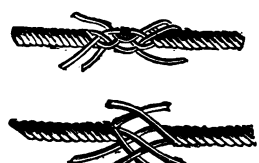


Fig. 44.—Short Splice.

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